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SMALL MACHINERY IN THE ARGENTINE REPUBLIC.

By F. A. MOFFATT, *Associate Member*, of the Argentine Republic.

[*Selected for Publication only.*]

It is with feelings of apology that the Author presents the following Paper, as it is not in any way of a technical nature; it treats of small machines in a commercial way only, and cannot in any sense be called an engineering Paper. Knowing, however, that manufacturing engineers are turning their attention to the South American markets as an outlet for their goods, it may be that some portion of the following remarks, although trite, will be of use to them. South America, it seems, is, as a rule, considered at home as one market, requiring more or less one class of article for the whole continent. If this be so, it is a mistake, and it is better policy to distinguish between the countries to be dealt with. Having had a number of years' experience in the Argentine, and knowing most of it, the Author proposes to treat of that country alone, in the hope that something of interest and use may be found in the following notes.

Both American and German competition is very keen in the Argentine, and in order to maintain a commercial footing and keep it, it is necessary to realize that the cheapness of an article is its principal selling point. This being so, the only way to attack such a market is to aim at supplying in large quantities, thereby

making cheapness possible. "Cheap" is a word which is generally associated with "nasty"; but this need not be so. The watches in use to-day are certainly cheaper than they were many years ago, but they are not necessarily nasty. Neither can the same be said of the Bosch magneto. Machines are made to serve a certain purpose, creating their own market, after the conditions and requirements of the community have been carefully studied, and when once it is realized that there will be a demand for a certain article, the manufacturer should aim at capturing the whole of the market in that line of goods. "A fair share" means either want of courage or else a lack of knowledge of the market. Such half-successful efforts have the dangerous effect of showing others the way. In small machinery it is necessary to alter and improve as often as possible; copyists cannot be prevented, however carefully an invention may be protected by world patents. It is better to go on improving, leaving copyists behind, which is what the American manufacturer aims at.

Practically every one who goes to the Argentine does so with the one idea of getting rich quickly, and leaving again. The working population, to a large extent, consists of Italians of little or no education, who know nothing of machinery or how to use it until they begin to deal with it here, and who never hesitate to buy the cheapest article offered. Should it turn out badly, the Italian will try the cheapest but one, and when at last he has found the article best suited to him, keeps to it—but he always goes into the details of price, even if he buys the same article twenty times running. This is more or less the type of customer found throughout the country, incapable of judging an article without trying it, and greatly carried away by a highly painted and gaudy appearance.

There is little manufacturing done in the Argentine, owing to the lack of metals, coal, and so forth, so that machine-tools are not largely in demand, and the trades are not very diverse. Generally, the following require a regular supply:—

Estancia work—that is, cattle and sheep farming.

Chacra work—grain producing.

Saw-milling and allied trades.

Wine making.

Sugar making and refining.

Repair-shop work and cart building.

The Estancia proper requires little beyond *Windmills*, of which there are thousands; approximately 93 per cent. are of American manufacture, with galvanized towers. They close automatically in high winds, and last with reasonable care from 10 to 15 years without repairs, being sold at prices which British manufacturers have never yet touched. *Two-horse mowers* are used, chiefly for alfalfa cutting, in the supply of which British manufacturers could and should hold their own, but at the present time only a very small proportion of British make is seen. *Rakes, hay elevators, presses, coaches, and carts* are practically all of American make. *Sheep-shearing outfits and cream separators* come from England, and *small motors* from all countries. *Dairy and cheese machinery* are imported from Denmark and the United States.

Motor-cars come from many countries, but few from England.

Chaff-cutters, previously almost exclusively from home, are now largely sent from the United States.

Pumps, from a hand-pump to a 3-inch or 4-inch centrifugal, are always being required as auxiliaries to windmills, and in time of drought large quantities are sold. Those most in demand are of the geared-head type, driving a single cylinder placed down a well, and connected inside the rising piping with galvanized piston-rod, avoiding stuffing-boxes except above land level. Pumps receive very severe treatment, often being required only for a month or two during the summer; they are left throughout the winter covered in sandy grit, and portable engines are brought to them when necessary, so that they are, comparatively speaking, of a rough and stout build. The estanciero is as a rule Argentine, British, or German, and the American, whose machines are seen everywhere, is conspicuous by his absence; this applies to a very great extent throughout all the machinery-consuming trades.

The *chacarero*, or grain farmer, is in many parts of the country only a renter of camp from the estanciero, who, when he requires alfalfa laid down or renewed, contracts with the chacarero to plough,

sow, and harvest, receiving in return either a percentage of the harvested crop, or else a fixed sum per year. As a rule, the chacarero has the first year to sow at least one-quarter to one-half of the land rented with maize or linseed. In the second year the unsown portion is sown with the same product, and the first portion in wheat; in the third and fourth years the whole is sown with wheat. With the last sowing, however, he sows alfalfa as well. Having finished the contract, he has to move on elsewhere. Latterly, as cattle have become scarce owing partly to tempting prices offered by the cold-storage companies and partly to the increasing prevalence of more speculative methods, the estanciero and the idle landowners have rented and re-rented to the chacarero. The chacarero rarely owns the land, and, always possessed with the idea of becoming rich quickly, he avoids making any building other than an "adobe," or mud-hut, to live in, and consequently constructs no shed or barn for storing either his machinery or grain. The chacarero is generally an Italian, who arrives without capital, and works and saves until he can rent or take on percentage contracts. He invariably rents or takes over not less than 90 hectares (1 hectare = 100 by 100 square metres) of land, and generally much larger tracts; he almost always undertakes larger pieces than he can handle, and scratches the land instead of ploughing properly. He often uses the worst class of broken seed, and harvests in the greatest hurry, never thatching a stack; then he thrashes the corn, and has to leave his sacks of grain oftentimes piled on damp ground with little or no protection, waiting until the store-keeper, to whom he invariably owes money, sells it to an exporting firm before it can be taken to the station sheds or disposed of. The store-keeper, usually a Spaniard, sells anything and everything, from a drink to thrashing sets, to the chacarero on credit, charging him 1 per cent. compound interest per month. A lost harvest or two soon gets the farmer into debt, which is fully taken advantage of by the store-keeper. The latter has consequently a good deal to say as to which mark of machine the chacarero buys, and until importers found it necessary to arrange prices and commissions, the store-keeper made the chacarero buy the article

carrying the largest commission off the price list. Most of this class of machinery carries a fixed 15 per cent. commission, and this rate is strictly adhered to by importers at the present time, who have bound themselves with forfeits should rules be broken. The chacarero, being a well-plundered person when he is down, and owing to the system of renting the land, does not erect sheds, and so a good class of agricultural implement is not required. As soon as the ploughing season is over, the plough remains where it was unhitched; the seeder, header, or binder, or even the thrasher, remains outside without any cover or care taken of it, serving during the off-months as chicken roosts. When times are good the chacarero becomes an owner of land, but he still shows the same careless disregard of machinery. The demand is and must be continuous, making it worth while to study the problem of supply on a large scale, and if the United States can turn out articles calculated to perform to a nicety the work they are expected to do, there seems to be no reason why the British should not be able not only to compete with them, but to surpass them in a trade which is continually increasing.

The Author has heard it stated that in Britain there are not the opportunities of studying agricultural machinery which are found in the United States. This might be said of sugar mills or gold-mining plant; but a few models carefully followed should be all that is required to keep the design right. Just as many people might be kept employed at home by small machinery making as by the manufacture of large and specialized articles. The chacarero requires large-capacity machinery of not very durable type, but attractive looking, and he needs careful systematizing of repairs. British portable and traction straw-burning steam-engines, thrashers, and large maize-shellers are still pre-eminent; but powerful American combines are at work in the Argentine which will not rest until they have captured everything—and only the greatest care and attention will prevent this happening.

Stripper Harvesters from our Colonies have met with great success in the south of the Province of Buenos Aires and Pampa. These machines strip and bag the grain in one operation, and are

being watched carefully by the American firms who have brought down similar machines and made trials on the spot, retiring apparently from the competition. The Americans do not want to supply a few dozen machines in an imperfect state, but once convinced that they have the right article, they will produce their hundreds, having gained the necessary knowledge on the ground itself. The usual American system is to send a few trial machines, probably copied from an English one, with an expert in charge. Very often their first machines are a mere rough sketch, badly constructed and worse finished. But the idea is to build from that, by first-hand knowledge of breakdowns, and criticism, something that is already on the road and is required. Still the expert follows the next lot of machines sent, carefully noting, tending, and gathering data, until the completed design is ready; then, judging the capacity of the market, he returns home, and, with those who sent him, sets about arranging for automatic machinery capable of turning out sufficient to supply, say, one year's demand. The expert still follows the machines, and probably getting a post in the house of the importers, and visiting the factory in the off season, keeps himself up to date. Then if the business is large enough and warrants it, he brings one or two factory men to follow the machines outside, who also are called experts, but who, in fact, are often merely men trained thoroughly in that one article, from whom little is hidden; weak or doubtful parts are their care, as well as the watching for improvements suggested by users. Then in probably one year the model is changed, embodying all improvements; and from a ramshackle article, little more than a rough model, within the course of two or three years at most a perfected machine is produced, which, defying competition, has come to stay.

All this is known and makes poor reading, but the points the Author wishes to bring out are the intention of capturing a market, the energy which does not leave machines to look after themselves, and the willingness to spend time and money to attain that end; it is these points which make competitors successful. It may be said that the British importer in the Argentine should look after

the supplying of information to those at home, and keeping them up to date in requirements. Although this may be so, it is not always possible, as the importer is not generally a person who understands machinery, and is perhaps unwilling to make detailed suggestions by letter for fear of appearing ridiculous. Again, he is a much sought-after person, and the American trained in his special line persuades him, often against his will, to drop British goods in favour of those from the States. The American machines are lucidly explained in "catchword" details by some one in personal touch with the factory represented, knowing its ways and means, and capable of parrying absurd suggestions, but ready enough to pass along the suggestion of any genuine improvement. Such attention to complaint is much more likely to gain and hold the sympathy of the importer, and he feels he is being backed up and assisted. The type of expert, or his assistant selected, is a young man who is willing to go thoroughly into the matter when there is trouble, and who discovers the remedy, which he passes along to the factory. In following most classes of small machinery, he may have to live in most filthy ranches, eat food full of garlic, or stay in a so-called hotel in a camp town where his bedroom has probably four or five other men occupants, to say nothing of a bed full of vermin. It is with the feeling of a missionary that the average American expert goes about his work, determined that every moment of his valuable time shall be made profitable. He has gone out to dispose of his machinery against all comers; he is always ready to learn, and has an eye to copying any improvement he sees in a competitor's machinery. The over-zealous man is very seldom seen here as a "missionary" expert. Some of our men, intended to fill more or less the same rôle, on the other hand, although well up in their particular article, strike one as having "side," do not easily dispense their information, and generally appear to be there as objects of admiration. There is a group of schools at home, to which the sons of British parents are generally sent, for the object of finishing off their education. The right type of lad can sometimes be met with in one of these. He knows both languages and both countries. These lads could be kept

in touch with, and, when ready, made use of. There are not many British machinery importing firms who deal with home goods exclusively—this is especially so in agricultural articles—the general rule being combined English and American houses, the latter side of which is generally ruled and backed up by strong combines. This feature makes it difficult for the British manufacturer to attempt the market on anything like a large scale, as he is aware that the American capitalist behind the rival goods is able and willing to fight to a finish; but, on the other hand, there is little doubt that the firms here would willingly drop the American article for the British the moment they saw something safe offered. American combines are great bullies, and the first serious attempt to touch their market would mean their coming down in full force and opening their own branches; and owing to the close touch in which they are with the retail market (their experts having supplied them with full data, such as the names and standing of the store-keepers and agents), they would be in a position to pick up and continue their business without abnormal interruption. Indeed, there seems to be every probability of the British houses having their American agencies withdrawn from them in the near future, seeing that the International Harvesting Company, Rumney Pull, and others, have already opened headquarters in Buenos Aires, and are slowly withdrawing their goods from the weaker firms.

After the War is over, therefore, and when new fields are being sought or old ones regained, there is a trade in this country worth fighting for as an outlet for British goods, with British firms at this end very willing to help them. But no firm or group of firms (unless willing to lay out sums sufficient to ensure a certain return) should seriously make the attempt, as such efforts, unless powerful enough, are apt to lead to improvements in designs costing time and money, which are then only taken advantage of by the watchful competitor. A group of firms covering a number of different machines, each one with its own speciality, would, by combining efforts, be more likely to succeed than by individual attempts.

With the "knockabout machine" slightly softer castings than those often supplied by British makers would be an advantage, as the treatment here is as a rule most severe, the hammer being the average mechanic's only tool. Americans fully realize this, and take great advantage of their many natural gas-wells to make almost everything malleable.

After the agricultural trades come a number of smaller ones, which call for a certain number of small machines, besides those which, once installed, require few renewals, such as power stations, flour mills, sugar mills; but as the Author wishes particularly to treat of trades that constantly need renewal machinery, he will leave the others out.

Saw-mills.—There is a fairly large number of these in the northern camps, run a good deal under contracts by land companies who let out "exploiting," which generally means felling the largest and most valuable timber, leaving the rest for clearers. It is unnecessary to enlarge on the different classes of wood, as they are well known to anyone interested in such work. Quebracho, a most important product, is greatly sought after for using as sleepers, large gate-posts, and wire-fence posts, as well as for reducing from the log to saw-dust, and shipping to Germany and the United States for the extract used for tanning purposes. The cedar is not of great value, being surpassed by that of Paraguay. There is also lapacho, a heavy and durable wood used for cart-frames, wheel-rims, and spokes. Steam tree-fellers are not practicable, as the undergrowth and smaller trees are not cleared at the same time as the large ones, making it impossible to penetrate with cumbersome machinery. Natives as well as Indians do a good deal of felling, squaring, and bringing wood into the saw-mills, which are often run by Italians who, after working for a while in the forest, move their outfits nearer the timber. Portable steam-engines with large fire-boxes are greatly in evidence, and generally bear a British mark; a cross-cut squares off the ends of the softer timbers, and the circular saw, of simple but strong make, cuts them into planks. The alternating vertical saw is not used so much to-day as formerly, and the band-saw, invariably a Panhard or Guillet, does the trimming of the

planking. The quebracho requires little or no touching, as the native is capable of squaring admirably with hatchet or axe.

Where stationary engines are used, British engines show up well, but an engine made in the country copied from the Sulzer (Swiss) make is seen occasionally. Fixed boilers of Babcock and Wilcox manufacture, together with its German copy, are mostly used. Steam traction-engines for hauling trees down, where the exploiting is combined with clearing, completes the list of the general run of machinery required. In the case of these latter engines the Americans were unsuccessful in their introduction of a new article, the centre of gravity being too high, and the tendency was to fall over rather than to travel in a vertical position. Inserted tooth saw-blades, although wasteful in saw-dust, are beginning to be fully appreciated by saw-mill men.

In regard to the saw-mills in the more southern parts, beginning at Santa Fé downwards, and to the wood-working trades in general, one finds the band-saws of German make, as well as the planers, thicknessers, moulders, and grinders, whereas previously English and French machines were in the large majority. Undoubtedly the German article is fitted for the work and stands up to it well, but the chief reason for the change is the system of credit extended by German firms, two years being the time allowed for payment in six-monthly, three-monthly, or even one-monthly instalments. Notwithstanding the supposedly large interest charged in the price of the machines, the total amount in many cases is far below anything at which the British can offer similar machines. It is on very rare occasions that one ever hears a complaint about German machinery in the wood-working trade; and although the Germans may be copyists, on examining their machinery one can generally find later patterns than amongst ours. There is a fairly large sale to be counted on for the 36-inch band-saw, complete with fence, double or fork top-bearings, of solid appearance, at from £24 to £55 net sale price, including importers' charges and profits. Also in use are 12-inch planers and thicknessers, and 4-inch to 5-inch single vertical moulders of the ordinary simple and strong design.

Frequently the blacksmith and carpenter are combined in one shop, and, of course, nearly every village has such a shop, its principal work being the building and repairing of heavy carts, in which case a drilling machine tyre-bender and welder are required, and occasionally a screwing machine having right- and left-hand dies, together with a 6-inch or 7-inch centre lathe with a 12-foot length of bed.

Although British lathes have stood the test of time and are considered good, the German article, with its attractive finish, has lately had a large sale. No doubt the lasting qualities are not to be compared with the home-built machine, but price and finish (although the latter consists of a good deal of filling in the unpolished parts) should have a little more attention paid to them in our machines for these markets. It is unnecessary to add that the change-wheel plate should always show both standard and metric dimensions, and the 127-tooth wheel be supplied.

The motive power for large wood-working machine-shops is naturally steam, and in many shops up-country a portable engine is the rule. Small shops are generally run by naphtha engines, ranging from 3 h.p. to 8 h.p., though nearly all recent inquiries are for crude-oil engines, which will undoubtedly in the near future cut out the more expensive working naphtha engine. Every one hopes to be ready for the Comodore Rivadavia oil, which for this small work is as yet quite unsuitable; but as the imported oil is reasonable in price so far, this type of engine gains ground, and there is no reason why the British engine should not meet with the sale it deserves. Of the many engines the Author has seen up to the present time, he has not come across one with its instruction book or wall card in Spanish. This is an important matter, and ought not to be forgotten. The Author has been asked in England, when remarking on similar omissions, if French were not good enough for instruction and erecting books or notes. This is not so—the language understood and spoken in the country should be used in every case.

The next trade requiring small machinery worthy of mention is the Wine Trade, principally carried on in the Province of Mendoza,

and to a lesser extent in San Juan, Catamarca, and Rioja. Until lately the Mendoza trade has been a most successful one, producing annually 2,000,000 barrels (of 200 litres each), all of which is consumed in the country. The profits have been very high, 30 per cent. being made year by year. The large majority of "bodegueros" or wine-makers, and viñateros or vine-growers, having risen from cartmen or small contractors, are as a rule very ignorant, but astute when buying; but as fortunes have been easily made, few of them saved for bad times. Instead of that they extended their holdings and capacities for wine until they appeared enormously wealthy (on paper), and went bankrupt when the crisis arrived, which happened before the outbreak of the War, and was due to mad speculation. Changes in Provincial Governments are not always a blessing, and as each party comes into power, the necessity of getting rich quickly "enthuses" every individual who has gained a post with an idea of looking after himself. Such an industry is at times bound to suffer depression from one cause or another and is left in a bad way, as in the present instance. Stocks of wine are never kept to any extent, most of it being sold before the following harvest; fortunately, there are not heavy stocks on hand just now, so that during the course of a year or two the troubled industry will doubtless flourish again, not as before, perhaps, but on rather a sounder basis. In this trade the Italian worker and bodega owner preponderate. There are a good many Frenchmen and a few men of mixed nationalities. Enormous quantities are dealt with, regardless of quality, and until recently the most poisonous stuff, with a high alcohol content, was sold, and sought after by the man who wanted the strongest liquor he could obtain for his money. Now, however, Government prohibits the addition of certain acids, and controls the quality, forcing the bodeguero to make the genuine article, which to-day is quite passable.

The rule has been in the past to put really good machinery down with little thought as to the cost, but for the next five years or so there undoubtedly will be a sale for cheaper goods. Some of the bodegas possess turbines, practically all made by Calzoni of Milan; and from steam-engines to suction gas, the larger

concerns have gone to Diesel engines, which can use the native Comodore Rivadavia oil, but it is found that imported oils are much cleaner in working. There are in the district of Mendoza about 2,000 bodegueros, with bodegas ranging from an output of 230,000 barrels down to 50 barrels per year, the smallest of which are still working by hand, and many with naphtha engines, which in time will be replaced by semi-Diesel engines. There are a large number of Babcock and Wilcox boilers installed in the wine establishments, as timber has been cheap, though now slowly rising in price. Vine trimmings and "orujo" (pressed skins and seed) are burned a good deal, so that steam is fairly cheap. Previously, nearly all the bodegueros used steam, as it was required for distillery work; but lately a duty of $25,000 Argentine gold (£2,200) has been put on all stills, with the object of preventing the making and adding of alcohol and water to the wine. Consequently, beyond a small boiler, with steaming capacity of, say, 100 to 300 lb. per hour, for cleaning out and steaming barrels, the boiler is not the indispensable article it used to be. Such an engine as the Ruston and Proctor semi-Diesel is almost ideal for the average bodeguero, and undoubtedly it will be seen taking the place of the small American naphtha engine. Could, however, a combination engine of this type be run on gas, produced from the vine cuttings and "orujo," it would insure the bodeguero against the sudden rises of prices in oil which are arranged by dealers, besides getting rid of refuse. The "orujo" consists of the skins and whole seeds after having been pressed under hydraulic or other machines up to 160 lb. per square inch. The Author does not know its calorific value, but thinks it is about the same as in France and Italy. A perfected engine from 10 h.p. to 40 h.p. working on crude oil, with interchange to gas produced by these two articles, each in turn, would ensure a sale of 100 engines probably within a very short space of time, and more to follow. The buying season for such engines as these is from October to March, but not during any of the other months. There would be no trouble in getting "orujo" sent home for trial purposes during the months of April, May, June and July, and vine cuttings or "sarmiento" from June till August.

The making of wine, although well known to most, may bear just a few words of description, as follows. The grapes, loaded in tubs, and brought in carts, pass over a weigh-bridge, which is of French or German manufacture. The weigh-bridges deliver stamped tickets to the carter, and are preferably of a type that has a locking platform of ample breadth, as the mules employed, owing to rough treatment, are very nervous. The grapes are then thrown into an armoured-cement tank, having holes directly over centrifugal separators, which separate stalks and leaves, and deliver the pulp containing unbroken seeds, skin, flesh, and juice to a vertical piston-pump. The latter is invariably of French make, having rubber spherical ball-valves, and works at a maximum piston-speed direct driven without gear-wheels; it has inverted pistons, with air-chamber on the top, forming a hinged inspection-cover, held in place with wing-nut and bolt. These pumps are of cast-iron with brass cylinders; they are not liable to corrosion, as the wine at this stage has little or no acid.

The pulp is pumped through either hose or other pipe to settling tanks of armoured cement or to Russian oak vats, manufactured almost exclusively at Nancy; the vats arrive in knocked-down form of 3-inch staves, all marked and in perfect shape for assembling. During the fermentation, the skins, etc., form a crust on the top, which must be kept moving in order to prevent heating. Recently automatic treaders or mixers have been introduced, which are proving only partially successful; they are designed to run along rails above the vats, or along the ground, with various kinds of arms. One German design is not unlike inverted umbrella ribs, plunged to the bottom and opening out as it rises slowly. At every few metres where electric power is installed, hanging plugs are arranged, so that current is available at all points.

The wine when fairly cleared is pumped off to other vats for further settling by portable electric- or naphtha-driven pumps, preferably of brass, as the wine in this, and during all following processes, attacks cast-iron. Of these pumps there is a large variety. The German pump, which has lately superseded the French type very noticeably, has spherical rubber ball-valves, which are always

an essential point, ready opening facilities, and large capacities. Brass centrifugal pumps do not seem to be used on a large scale; but probably one with an ample sized inspection hinged door would find a ready sale.

The settled pulp is extracted through a small door from the bottom of the vats and conveyed in small trucks (along a 60-centimetre light-rail gauge having turn-tables at all necessary points) to hydraulic, belt-driven, or hand-power presses, where the pressure exerted is from anything up to twelve atmospheres, the plungers working down into iron-bound wooden slat cages ranging from 90 centimetres to 1·2 metre diameter, and, say, 1 metre high, mounted on stamped steel trays. Although at the present time the hoops, bolts, and nuts of these cages are of ordinary iron, they should be coated with solder or other non-corrosive material, as painting, however carefully done, does not last long.

The pressed skins, etc., as well as the seeds (which latter must not be broken for fear of discharging the oil contained), are either passed along to the distillery, or used for burning, if the boiler is suitable, or just got rid of in any form. If distilled, the solid matter, together with the tartaric acid extracted from the acid water, is forwarded to Italy, Germany, France, England, or the United States for producing tartaric acid, being sent back again in that form for treating the wines in the fermentation stage. There is no successful factory in the country capable of manufacturing the tartaric acid of the purity required by law, which calls for from 99° to 99½° pure. It is unnecessary to add that the hydraulic presses must have an automatic knock-out or self-acting relief springs, for slowing down the rate of travel, as the mass of pulp solidifies.

The wine must be prevented from overheating during the fermentation and early settling stages, by circulating it by means of the portable pumps, passing the wine through thin piping laid down in troughs, through which the irrigating water is carried into the bodega for this and for cleaning purposes. These pumps are also used for passing the wine through the stages of rectifying, pasteurizing, filtering, mixing, and casking. Miles of good rubber-

hose pipe are required every year, in which the German has lately competed successfully with a cheap-priced hose of doubtful value. Brass connexions should always be of the following dimensions :—

31 millimetres (inside diameter) . . .	12 threads to the inch.
40 ,, ,, . . .	$9\frac{3}{4}$,, ,,
45 ,, ,, . . .	$9\frac{3}{4}$,, ,,

Above these sizes ordinary Whitworth standard pipe threads are employed.

Oak casks of 200-litre capacity are mostly used. They are supplied in bundles of five casks almost exclusively to-day by the United States, and are built up by hand at the rate of one per fifty minutes on the average, each man taking his own bundle, and going through the whole process of building. Owing to the not very perfect state of the staves and heads, which shrink and become oval to some extent, the top and bottom ends of the staves where the hoops do not bring the wood to wood, are filled in with strips of dried reed. The barrels are steamed by placing the bung-hole over a steam-jet, and are then ready for the wine. One or two attempts have been made to organize a factory in the Argentine for turning out barrels by means of modern machinery, but owing to the fact that the only timber which is really suited for the work is in a region in Patagonia with no railway to serve it, nothing has come of these attempts. Better means for assembling barrels no doubt could be devised, such as stave trimmers, hoop drivers, and so on; but until lately money has so easily been made that the time for improvement is only just arriving, now that the industry has received a shock through the present financial crisis and the European War. Each bodega has its own small laboratory for simple testing work. French instruments fairly held the field originally, but the Germans here, as with other articles, have captured the market.

There are numerous turbines working under low heads, ranging from 10 to 80 h.p., and as time goes on more of these will be required. The favourite mark, as stated in a previous paragraph, is Calzoni of Milan, and none should be offered in the Province of Mendoza unless comprising, or at the same time quoting for, an

efficient regulator. Small dynamos and motors are always in demand, high efficiency being not so much sought after as reliability and simplicity, for, with regard to such markets as these, it must be always borne in mind that the so-called mechanic or electrician is, as a rule, nothing of the sort, but a far more dangerous individual—one who pretends to know, but who is in reality the most ignorant destructor with hammer and chisel. The best-known dynamos and motors are those of Marelli of Milan, Siemens Schuckert, and the British Westinghouse and A. E. G., in the order named.

The landowners of Mendoza and San Juan, as well as of other provinces, are devoting much attention to fruit growing, but owing to the highly protective laws *re* sugar supplied from the Province of Tucuman mostly, and to a less degree from Salta and Jujuy, full benefit cannot be derived from this industry. If sugar were at a reasonable price, jams could be manufactured with satisfactory results. The sugar monopoly, besides keeping prices absurdly high, prevents the beet from being grown, so that, for the present, fresh, dried or tinned fruits are the only products of the fruit farms; and as undoubtedly an immense quantity of fruit will be grown in the future, there is room for study as to the machinery required for drying, tinning, and chilling. The fruit generally is of a poor quality, the Italian always seeking after quantity and not quality, and harvesting too early, with the object of catching an early market; the packing is badly and cheaply done, so that the ripe fruit is crushed and spoilt.

Water both for cattle and irrigating purposes is easy to obtain in many of the provinces, and the boring machine is hardly required throughout the central part and the east of the country. A hand force-pump, or pump driven by a small naphtha engine, a piece of rubber-hose pipe, a length of 1-inch ordinary gas-pipe with a hollow sharpened bit at the end, are all that is generally required to bore to a depth of 250 feet, owing to the hard-packed sandy soil with hardly any dividing strata. Water can usually be found at a depth of from 6 metres to 30 metres, a well being often dug to surface water with a bore-hole of 20 metres depth to ensure

a good supply; this is the ordinary class of well. A cylinder, connected to a windmill, generally then ensures an ample supply of drinking water for stock.

Taking a very rough average, artesian water throughout the north midland camps can be tapped from a depth of 100 to 250 metres, the injection system of boring being suitable, as there are no stones or rock to deal with. But in other parts, a percussion outfit having combined injection-tools to start with, or for passing any running sand, is the most suitable, to which the rotary attachment for turning the case-pipe should be applicable in case of necessity. The dry core boring, diamond head, or adamant, is little required for ordinary purposes, and the simplest built and probably most handy article of those the Author has seen and dealt with is the Armstrong machine of Waterloo, U.S.A., although not much known. For Uruguay this type of machine is what is required, as well as for the northern districts of the Argentine. Demand for these machines varies very considerably, and owing to the heavy rains experienced during the last year or so there is not much to be done. But should a drought take place, from which these countries have suffered severely in the past, a demand for the right machine would soon be created.

Roads outside the large capitals are of the worst type, except where Nature has provided the right class of soil and flat lands, and consist of a series of ridges made by cart wheels. This makes it necessary, in the case of a motor-car, for instance, to take into account the measurement from centre to centre of ruts; the clearance also must be about 30 to 35 centimetres under the car. The Americans have studied such details as these, and in consequence they have been most successful with both trap and car selling. Their lorries, steam-rollers, and so forth are more in evidence every day.

As may be gathered, there is an outlet for small British machinery, and as soon as the War is ended manufacturers will be looking to foreign countries which will be ready to receive their goods; but it must always be borne in mind that the consumer is of the "get-rich-quick" type, and will buy, as a rule,

the cheap article having the largest output. He is a man that understands little or nothing of what he is buying, and relies on the seller to explain from start to finish the machine in question; therefore, seeing that the average seller is often a clerk, typist, or nothing at all, and merely speaking Spanish, a full printed explanation is required with each article. A buyer at home, for instance, will be shown by the maker the good points and the reason why the machine is best suited. It is bought and forwarded to the Argentine and repeat orders come along. The native, or whoever it may be who happens to run that article, remembers a few descriptive phrases about it, but unless he is supplied with a simple catalogue that he can understand, he is apt to annoy the seeker after information, who is caught by the rival competitor. The catalogue should show the output in kilográms, litres, kilograms per hectare, and so forth, together with the h.p., revolutions per minute of the pulley, b.h.p. to drive, etc., instead of lb., bushels, cwts., nominal or even i.h.p.

Another point worth looking into with regard to the home-made article is that the maker does not wish to disclose the full capabilities of his machine. This is well enough in valuable machinery, and that which is required to last for a quarter of a century; our competitors, on the other hand, cut down to a near average output and h.p., so that, comparing article for article, the latter often appears 100 per cent. better. To give an instance. A certain centrifugal pump as listed by British makers showed a certain output. In actual practice, however, the pump would deliver 70 per cent. more with the given h.p. Taking the North American centrifugal pump of the same price, however, by catalogue it was found that 100 per cent. more water could be delivered by it as compared with the British pump. There is little doubt which machine the "get-rich-quick" man would buy, with the remark so often heard to-day: "Es inutil; hay que sacar el sombrero a los Americanos." (It is useless; you must take off your hat to the Americans.) The Author put the case to the makers, who saw the point immediately, and listed their new pumps, which were just ready for the market, with a 10 per cent. margin as to

output, and although he has been the means of selling quite a number of these pumps, he has always heard them praised.

Here again is a case where the so-called expert or factory man is useful. He notes in his mind or book the reason for the loss of every sale, and shortly he gathers a clear idea of what the reason is—be it one piece of a machine continuously arriving in a broken state, or breaking in the working owing to some local condition, want of instruction, lack of all proportion in price—in fact the real reason, and how to combat it. There is a large German firm in Buenos Aires which, on receiving a new machine or altered type of an old machine, makes it a rule that the chief salesman unpacks the first box, builds the machine, knocks it down again, and packs it ready for the chief mechanic, who in his turn goes through the performance and passes it along, and before the machine has started on its way to the consumer it is known, understood, and very often wisely criticized before having gone too far. This perhaps has nothing to do with the manufacturer, but what it is intended to point out is, that our competitors are keen, and are not apt to let details slip.

Packing.—In some instances the packing of British goods leaves a good deal to be desired, the packers being too fond of building a case round a machine and filling it with shavings, the merchandise arriving in the worst possible condition in consequence. Much could be written drawing comparisons between British and American methods. It is at the wayside stations that the damage is done, and the rule is that all cases can be turned over and over and let fall on the flat, but must not be dropped on one corner. This is no exaggeration whatever, and so long as the system exists—no matter how clearly the words are printed in English on the case, "not to be dropped from cart or lorry"—and so long as other countries can and do pack to withstand this rough usage, the British must change their methods of packing to withstand the treatment referred to. The Author knows of firms in the United States which pick out at random a fixed percentage of their packed machines, generally 8 per cent., deliberately turn the cases over end for end until the "dropping platform" is reached, tip

them over on to the ground, provided with railway rails for them to fall on from a 1 metre height, then lift up a board or two to examine for breakages or any movement of the machinery.

Few machines in the Argentine are sold or known by the name or mark of the maker, but the importers have to register their own marks and apply the names they have so registered to the different machines; so that should the makers for any reason or other change their agents, the machines, if sold under another name, would get lost sight of completely. Therefore, where feasible, the maker's name should be shown on the principal casting or other prominent part, unless it be some name unpronounceable to a foreigner, in which case some identifying name should be shown, one that can be as easily pronounced by a Spaniard as an Arab. Every machine or article should come packed with clear and simple instructions, as set forth in an earlier paragraph.

The term "expert," as pointed out in the Paper, does not mean what the word literally implies, but one who has been carefully trained in the use of the machinery he is sent out to set up, watch, protect, perfect for local conditions, and increase the sale of. It is not to be supposed that the factories are to do all the advertising in the country to which the manufacturer is exporting, but if he merely supplies descriptions by letters, which are read by one man possibly and then filed away, he can never expect his articles to be thoroughly understood or appreciated. Blocks for newspaper advertising and local catalogue work should be supplied, and the same care taken with a foreign firm as one would expect from a Persian or Russian attempting to introduce an article by correspondence into England. Every article should come packed with clear and simple instructions in Spanish, printed where possible on a varnished card, with repair parts on the back, placed in a closed envelope with the words "Entregar al dueño" (Hand to the owner), so that in as many instances as possible the card may arrive in the hands of the owner and not be torn up by the erector, with the object of covering his ignorance if he has trouble, or keeping knowledge to himself.

MODULES AND UNIFORM DISCHARGE DEVICES FOR IRRIGATION AND WATERWORKS.

By HUGH MUNRO, *Member*, of Glasgow.

[*Selected for Publication with Discussion in writing.*]

The equitable distribution of water has been, from the earliest times, a problem of importance both to irrigation authorities as well as to the consumers of water. If any system for the accurate measurement of water had been known to the ancients, it has apparently been forgotten, the methods in use by their descendants being crude and primitive. In Northern Italy and in Spain irrigation has been practised for centuries, and in these countries methods for gauging discharges from canals have been developed at an early date to a fair degree of accuracy.

In the year 1570 the Municipal Council of Milan invited engineers to submit proposals for improving the system of water distribution, as the methods in general use were very unsatisfactory to all concerned. The designs of Giacomo Soldati were adopted, and the form of outlet introduced by him is now known as the Italian module. It possesses many advantages, and, improved by modern knowledge and skill, it has, in many forms and under various names, been adopted in districts where water is valuable and where accuracy is therefore essential. The device is, however, non-automatic and requires regular attention on the part of the

canal officers, who alone are permitted to adjust it when the supply-water level in the canal renders that operation necessary.

Irrigation engineers have long attempted to produce a module which would discharge water automatically at a uniform rate, and thus be independent of variations either in the supply- or discharge-water levels, and it is obvious that such a device would form a very accurate water-meter when the length of time is known during which discharge has taken place. But where water is scarce and valuable, and in newly-developed districts where there is an opportunity of introducing scientific methods of distribution without opposition, it is probable that some simple form of meter will be introduced in the future, so that each consumer may pay for the actual quantity of water which he uses.

It is no easy matter to design and make a module which will operate satisfactorily under the many and varied conditions existing in irrigation practice. In waterworks, where conditions are less exacting, several types are in use with good results, but it is doubtful if irrigation engineers have found even one type to approach their ideal of a successful module. Many different designs have been made and tried with more or less success, and the object of this Paper is to describe a few which have come under the Author's notice during a number of years while engaged in the design and manufacture of these and similar hydraulic devices. Some of the designs presented here are already well known to engineers, and among them are included types of apparatus which, while not adapted for irrigation, are in common use at waterworks for equalizing the discharge from filters, and for other purposes.

The chief factors to be considered in the design of a module are as follows:—

(1) Quantity of water to be discharged.
(2) Possibility of being tampered with by unauthorized persons.
(3) Consumer should be able to see at a glance whether or not he is getting his correct supply.
(4) Range of variation of head on inlet and outlet of module.
(5) Loss of head which may be permitted in the module.

(6) Degree of accuracy required.
(7) Amount of silt and floating matter in the water.
(8) Possibility of having to change the rate of flow after the apparatus has been installed.
(9) First cost and maintenance.

On the first point no comment is necessary. As regards the second, modules are always liable to interference by interested parties, and therefore the essential parts should be simple and well protected from wilful damage.

Facility in Observing Correct Supply.—It is important that mere inspection should show if the discharge is correct. The usual method adopted is to pass the water through an orifice under a constant head which is indicated by a fixed mark, by which the consumer may see at any time, and without measurement satisfy himself, that he is receiving his correct supply.

Range of Variation of Head, and Permissible Loss of Head.—The loss of head which may be permitted in a module determines to a great extent the type to be used as well as the size. Where the canal water-level is only slightly higher than that of the surrounding land, the loss of head in the outlet must be reduced to a minimum in order that the canal may command the higher lands. All modules consume a certain amount of head, and when the canal water is at its lowest level the discharge issues at a level which is still lower by the amount of head thus lost. Some modules must always discharge at this low level, and if the supply water rises, advantage cannot be taken of the additional height without reducing the rate of flow. Others give their correct discharge with a constant loss of head, and when the supply water rises by a given amount, the level of the outflowing water may be raised to the same extent. In districts where there is high land which can only be irrigated when the water in the canal is at a high level, the latter is therefore the type of module to use, and it should be designed to have the loss of head as small as possible.

When the water-supply is plentiful and at a high level in the canal, it may be desirable to give consumers a greater quantity than their normal supply. Some modules may be made to give a discharge which increases automatically at a definite rate as the level of the supply water rises, without complicating the apparatus.

The variation of level in canals is usually of small extent, while in reservoirs it may amount to over a hundred feet, but with a suitable instrument the rate of flow may be maintained nearly uniform throughout any range of level.

Degree of Accuracy required.—The degree of accuracy to be aimed at depends on the value of the water. If it is plentiful and cheap, there is usually no necessity for an accurate instrument, especially if additional accuracy adds to the cost of installation. In newly-established districts where water is cheap, but likely to become more valuable in the near future, a proper system of distribution should be introduced at the beginning.

Amount of Silt and Floating Matter in Water.—Silt should have no effect on a well-designed module, but if moving parts are included in its construction, floating matter, especially twigs and long grass, would probably cause trouble, and ought to be caught on a grating at the inlet to the supply pipe. Where silt is present, the water should be drawn off at or near the bottom of the canal in order to prevent deposits forming in the waterway.

Possibility of Changing Rate of Flow after Installation of Apparatus.—After a module has been installed, it may be found desirable to alter its rate of discharge. With some types this may easily be done by the canal officer who, after making the change, seals the apparatus so that it may not be interfered with during his absence.

First Cost and Maintenance.—The question of first cost and maintenance depends largely on the value of water in each district. If it is scarce and valuable, more accurate and higher priced instruments may be used than if water is comparatively cheap.

In the following descriptions of modules the drawings are mostly diagrammatic, and are only intended to illustrate the principle on which each one works. The descriptions are confined as far as possible to devices containing not more than one moving part in their construction. A few modules have no moving parts, but these are more limited in their range than those with one moving part, and as a rule their discharge cannot be altered so conveniently as that of the latter type. Where moving parts exist, the reduction of friction is an important consideration, and with care the friction may be practically eliminated.

Weirs and Orifices.

Ordinary weirs and orifices are more extensively used for the accurate measurement of irrigation water than any other types of apparatus. Usually each outlet is made of a definite size, and a uniform rate of flow is maintained by keeping a constant head over it. For this purpose automatic devices are in use to a limited extent; in the majority of cases each outlet is visited at regular intervals by an official who regulates a control sluice.

Italian Module, Fig. 1 (page 512).—This is the oldest non-automatic type, and consists of a chamber *a*, having an orifice *b* in one side. Water is admitted to the chamber from the canal *c*, through an adjustable sluice *d*. The canal officer brings the water-level to the correct height above the orifice by adjusting this sluice, which is locked in a fixed position during his absence. The chamber *a* should be of such a form and size, and fitted if necessary with baffles, as to reduce to a minimum the velocity of approach to the orifice. With a correctly dimensioned orifice and an efficient stilling chamber, this arrangement forms a very accurate meter, provided the official who adjusts it is strictly impartial, which unfortunately is not always the case.

The amount of head lost in this device is considerable, but it may be reduced by using a weir instead of an orifice. A submerged orifice reduces the loss of head to a still greater extent, but it is not looked upon with favour by irrigation authorities. It is not so

Figs. 1, 2, and 3.—*Non-Automatic Devices.*

Fig. 1.—*Italian Module.*

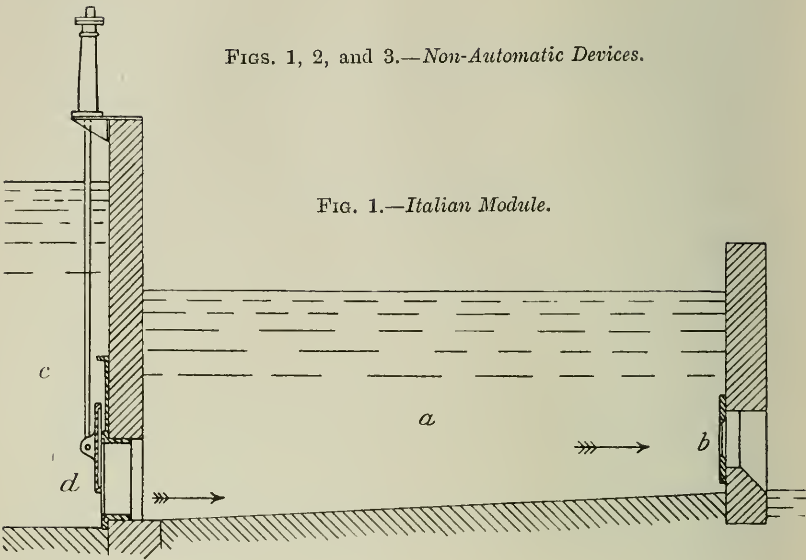


Fig. 2.

Regulating Device.

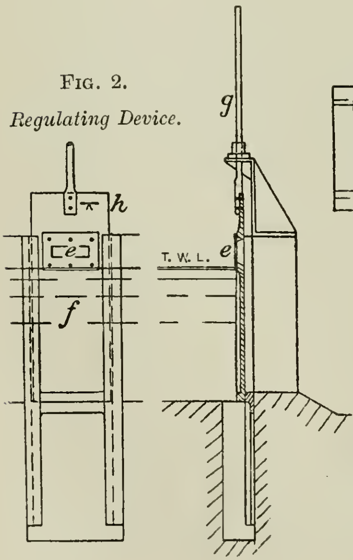
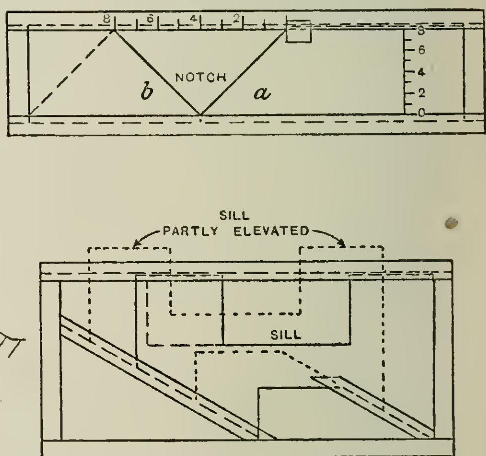


Fig. 3.

Adjustable Weir (Harrison).



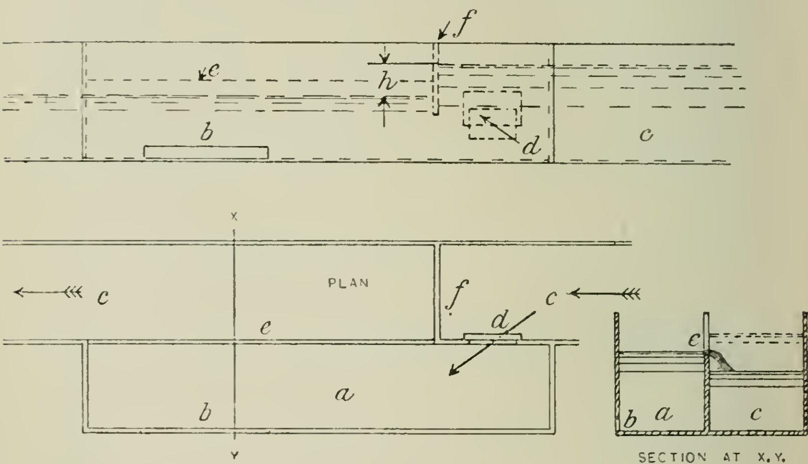
convenient to regulate as an ordinary orifice, seeing that there are two levels to be observed in adjusting the flow, and, in the absence of the canal officer, the consumer may lower the downstream level and thus obtain an increased supply.

In all devices based on the principle of the Italian module—which, under various names and in many forms, is to be found all over the world—there is a certain amount of variation in the level of water above the final outlet corresponding to the variation in the main canal, with a consequent variation in the rate of discharge. Since the discharges from plain or submerged orifices, rectangular weirs, and V notches, vary respectively as $h^{\frac{1}{2}}$, $h^{\frac{3}{2}}$, $h^{\frac{5}{2}}$, where h is the head over the orifice, or weir sill, or apex, it follows that, working under a varying head, a V notch gives a less uniform discharge than a rectangular weir, and the latter a less uniform discharge than an orifice. Further, the greater the head over an orifice, or the greater the ratio of the head over a rectangular weir to its length, the more uniform will the discharge be under variations of head.

Unwin shows that, in the Italian module, the intermediate chamber *a*, Fig. 1, has got no regulating effect apart from the adjustment of the sluice *d*. Consequently if the orifice were placed directly in the canal and manipulated by the attendant, the result would be the same as that obtained by the use of the Italian module. Fig. 2 shows how this arrangement may be carried out; the orifice *e* is set in a shutter *f* which may be moved vertically by means of the screw *g*. The correct height of the water above the orifice is indicated by a mark *h* on the shutter, and the canal officer is thus enabled to adjust the orifice to the proper depth under the surface. The intermediate chamber is dispensed with in this design, and, while possessing the merits of the Italian module, it has also the following advantages: it is cheaper to construct; it can be adjusted without loss of time; when the water-level in the canal is high, the discharge may be raised to a corresponding extent. With muddy water the depression into which the shutter sinks may become silted up, but with some care this may be avoided.

Harrison's Adjustable Weir, Fig. 3 (page 512).—This is another form of non-automatic outlet. In the V notch one side *a* of the V may be traversed horizontally past the other inclined side *b*, with the result that the vertex may be adjusted to any required depth under the water surface. In the case of the rectangular weir the sill is also traversed horizontally, and the necessary vertical movement is given to it simultaneously by an inclined plane underneath. The necessary movement of the sill or vertex could of course be effected directly by a screw, but at increased cost. The sliding plate is

Fig. 4.—*Simple Automatic Module* (Foote).

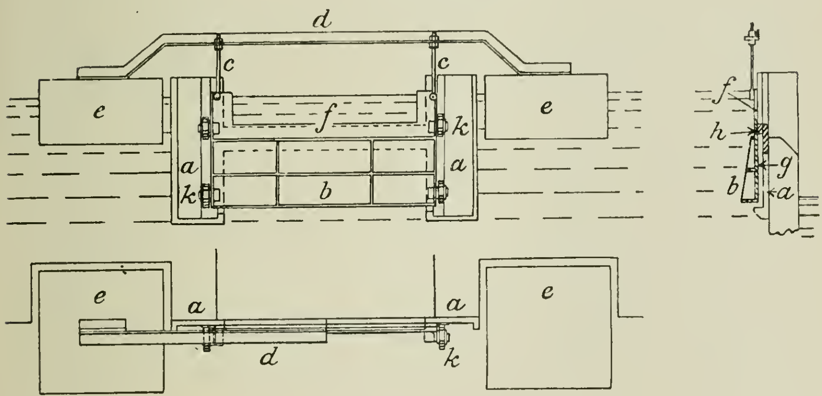


usually made with sufficient travel to shut off the water altogether, so that the weir may also be used as a sluice. It will be seen that this device is suitable only for moderate variations in water-level.

Foote's Module.—Many attempts have been made to keep the head constant over a plain orifice automatically. The simplest device of this kind seems to be Foote's module, Fig. 4. In this illustration, *c* represents the main channel, *b* the discharge orifice, *d* the sluice controlling the flow from the canal into the orifice

chamber *a*. Downstream from *d* the water-level is lowered by the amount *h* in the main channel, by means of the weir *f* placed across it. The sluice *d* is opened more than is necessary to give the correct discharge, and the excess water flows from chamber *a* over a long weir *e* and back into the main channel at the lower level. Thus the head over the orifice is kept very nearly constant, and the rate of discharge is practically uniform. It is not always possible to get sufficient fall in a canal to make use of this device for every consumer, but by taking several supplies off at one place the loss of head is reduced as well as the cost.

Fig. 5.—*Floating Weir.*



In other methods for automatically keeping the head constant, valves are used actuated by floats in the orifice chamber. As the valve must be capable of opening through its full extent with a very small travel of the float, it may either be of an equilibrium type with multiple ports and a very large float, or the main valve may be actuated by a pilot valve operated directly by the float. The latter arrangement is used with a high-pressure supply; the equilibrium valve is more suitable for low heads.

Floating Weirs, Figs. 5 and 6.—Floating weirs, both straight and circular, are frequently made use of, especially in waterworks

practice, to maintain a uniform discharge. Straight floating weirs may be made almost any length, but their accuracy depends on the size of floats and on the efficiency of the friction-reducing devices. In Fig. 5, *a* is a fixed frame, *f* is the sill of the sliding weir-plate *b*, which is carried on adjusting screws *c* and on the beam *d* by floats *ee*. In order to reduce leakage, the sliding plate is machined all over the rear face *g*, which almost touches the opposing machined face *h* on the fixed frame *a*. The pressure on plate *b* is transmitted to rollers *kk*, which run on machined paths on the fixed frame.

FIG. 6.—*Circular Floating Weir.*

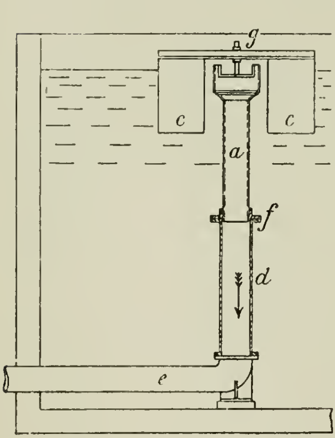
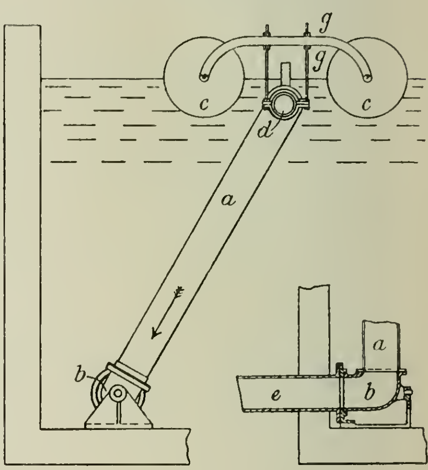


FIG. 7.—*Floating Orifices.*



This apparatus is suitable for small or large volumes of water and for moderate ranges of level. Silt in the water interferes with the action of the rollers and increases friction, but with clean water the arrangement is fairly accurate.

Fig. 6 shows a circular floating weir, consisting of an upright pipe *a* carried on floats *c*, and sliding inside a larger stationary pipe *d*. The water flows over two rectangular weirs placed on opposite sides of a box carried on the pipe *a*, falls into the interior, and is discharged through the pipe *e*. The thin upper end of the sliding pipe may itself act as a circular weir, the box and rectangular weirs

being dispensed with. Leakage is reduced by a neatly fitting gland *f* where the sliding pipe passes into the fixed one. The discharge may be varied by adjusting the height of the weir relatively to the floats, by means of the suspending screw *g*.

Floating Orifices, Figs. 7, 8, and 9.—Many devices similar to that shown in Fig. 6 have been proposed having, instead of weirs, one or more orifices discharging into the centre pipe, the top of which is higher than the water surface and open to the atmosphere. A somewhat different device in general use—but for other purposes than that of maintaining a uniform discharge—is shown in Fig. 7. The pipe *a*, supported at the base by the swivelling elbow *b*, has its other end carried on floats *cc* which maintain the orifices *d* at a constant depth under the surface. The rate of flow from this apparatus at *e* increases slightly as the water-level falls, and to counteract this variation the floats should be made large. The depth of the orifices under the surface may be varied by adjusting the screws *g*, and the pressure in the interior of the pipe *a* must be atmospheric.

Another form of floating orifice consists, Fig. 8 (page 518), of a siphon *a* carried on a float *d*, and having one leg immersed in the supply water, while the other is suspended over the side *b* of the tank *c*. The flow through the siphon must be started by artificial means, and the discharge remains uniform provided no air obtains admission to the siphon. This apparatus is in use to some extent for regulating the flow from slow sand-filters at waterworks.

In Fig. 9 (page 518) is shown a form of floating orifice different in principle from those just described. A vertical pipe *b* slides inside another fixed pipe *a* through a gland *d*. Water is admitted to the inside of *b*, and passing upwards discharges through the orifices *c*. The rate of flow increases until the pressure inside *b* is sufficient to float that pipe upwards. Thereafter the discharge remains uniform, seeing that the head at the orifices is constant, determined as it is by the weight of the pipe *b*. Like the device shown in Fig. 6, the range of the present one is limited, and it is not well suited for water carrying silt. The discharge may be varied by adjusting the weights *w*.

Adjustable Orifices.—Adjustable orifices, controlled by floats, are in use to a limited extent, but they are unsatisfactory for accurate measurement. The Spanish module, Fig. 10, is one of the simplest of this type. It consists of a plug *b* of special form, hung from a float *a* and passing through the orifice *c* in the bottom of the chamber *d*. As the water-level rises or falls, the float causes the

Fig. 8.

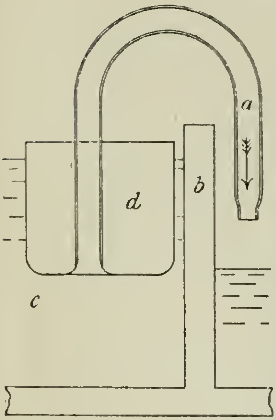
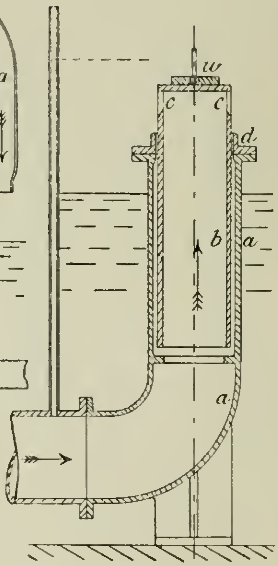


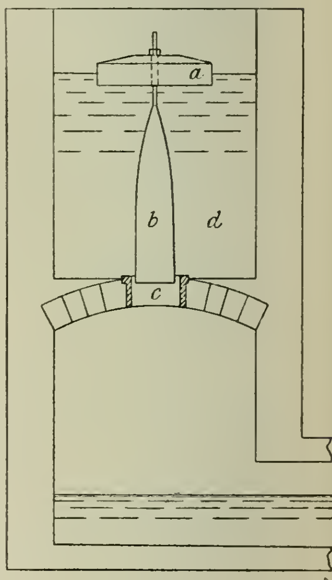
Fig. 9.



Floating Orifices.

Fig. 10.

Simple Adjustable Orifice.



plug to travel through the orifice, and by diminishing or increasing the area of the latter a fairly uniform flow may be maintained. A great amount of head is lost in this module which is suitable only for a moderate range of level, while in order to obtain good results the float must be made large.

A more common form in which the variable orifice appears consists of a sluice or valve—usually balanced—operated by a float through the medium of a lever and cam. The cam, actuated by the

float and lever, opens or closes the valve by the amount required to maintain the discharge uniform as the water-level falls or rises. In all such devices the friction of the gear, as well as the approximate value which must be taken for the coefficient of discharge when calculating the form of the cam, introduces elements of inaccuracy into this design.

Piston-Controlled Valves.—There are a number of devices in which the difference of pressure on the two sides of a piston, exposed to the water on the upstream and downstream sides of an orifice, operates an equilibrium valve and thereby maintains a uniform rate of flow. Fig. 11 (page 520) shows one design in which water is discharged into a tank *f* through an orifice *e* under a head which is kept constant in the following manner. An equilibrium valve *a* working vertically is suspended from a piston *b* which moves freely in the cylinder *c*. The lower and upper sides of the piston are in communication with the upstream and downstream sides of the orifice respectively, and the difference of pressure on the two sides of the piston is sufficient to keep it and the valve floating. Should the supply level rise, there will be a tendency towards increased flow, along with a greater difference of pressure on the two sides of the orifice and of the piston. The latter will immediately rise and reduce the area of the valve ports, thus restoring the difference of pressure to its normal amount, when the piston and valve will again float in equilibrium, but in a new position. The reverse takes place with a fall in the supply water-level. Thus no sooner does the discharge tend to vary, due to a change in the supply water-level, than the valve at once adjusts itself to maintain the flow at its normal and uniform rate. In the illustration the valve is shown discharging into an open tank. It may also be used in a pipe-line, and the dotted lines show the connexions required in that case. Fig. 12 indicates the result of a test made on a valve of this description.

Figs. 13 and 14 (page 522) illustrate a device similar to the last, but in which the fixed orifice is dispensed with. Water enters a cylindrical casing *a* through ports *b*, and passing upwards through

the annular space c is discharged at the top. When the upward velocity of the water attains a certain magnitude the difference of

Fig. 11.

Piston-Controlled Valve.

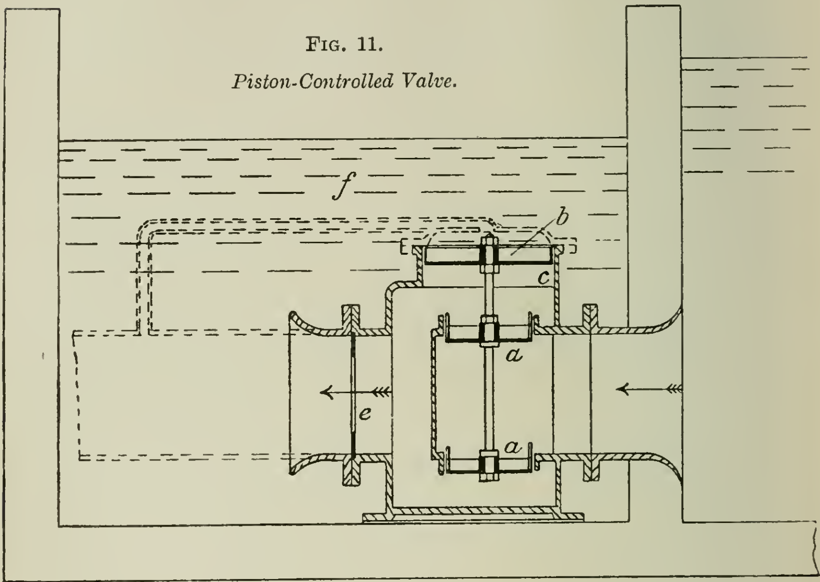
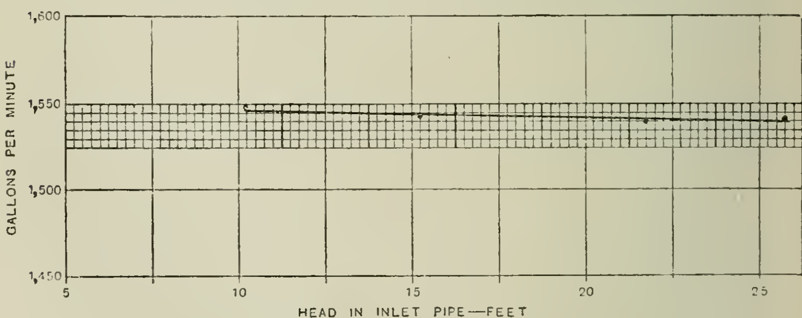


Fig. 12.—*Result of a Test made on above Valve*, Fig. 11.



pressure on the two sides of the piston f is sufficient to cause the valve e and piston to rise and partly close the valve ports, and

thereafter to hold those parts (the piston and valve) suspended. The mode of operation is exactly the same as described for Fig. 11, the orifice in this case being the annular space between the piston *f* and casing *a*. There is no leakage in this device, and all the discharged water serves to actuate the controlling piston, the direction of flow being indicated by arrows.

By increasing the diameter of the piston, as in Fig. 14, the loss of head may be very much reduced, but to obtain the greatest possible discharge with a minimum loss of head, the piston should be replaced by a part having some flotation effect, and termed a float, as in Fig. 15. Here the valve is connected to the float by a pipe *n* which, working over a centrally fixed bolt *p*, acts as an almost frictionless guide. The dimensions on Fig. 15 are those of a module which will pass ten cubic feet per second with a total loss of head not exceeding $5\frac{3}{4}$ inches. The discharging capacity varies with the loss of head permitted, and the curves in Fig. 17 (page 523) show the limits within which this module operates. The valve is not constructed to shut the water off altogether, and the lower curve shows the relation between rate of discharge and loss of head when the valve is at the upper end of its travel; the upper curve shows the same relations when the valve is at the lower end of its travel and full open. Any discharge between the limits set by these two curves may be obtained by giving a suitable weight to the valve and piston. For instance, the module shown in Fig. 15 will discharge 1·8 cubic foot per second, with 0·2 inch loss of head, and it will continue to maintain this rate of discharge until the loss of head is 14·5 inches. At this point the valve reaches the upper limit of its travel and becomes inoperative. The discharge begins to increase as indicated by the part *b d e*, Fig. 17, of the lower curve, and the complete curve of discharge from zero loss of head is *c a b d e*. By increasing the weight of the valve and the attached parts any greater rate of flow may be obtained, as, for instance, 6 cubic feet per second with a minimum loss of head of 2 inches, or 8 cubic feet per second with a minimum loss of $3\frac{1}{2}$ inches, etc. Constructed with a piston $\frac{1}{16}$ inch thick, instead of with a float, this module would operate only with discharges of 10·4 cusecs and

Piston-Controlled Valves.

Fig. 13.

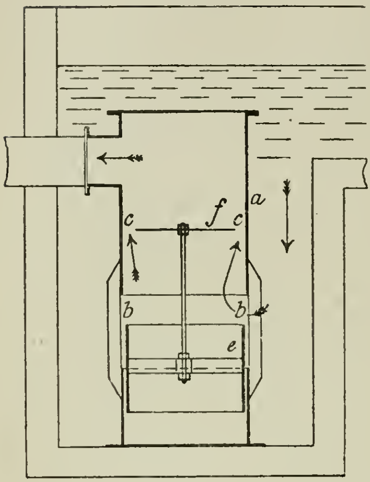


Fig. 14.

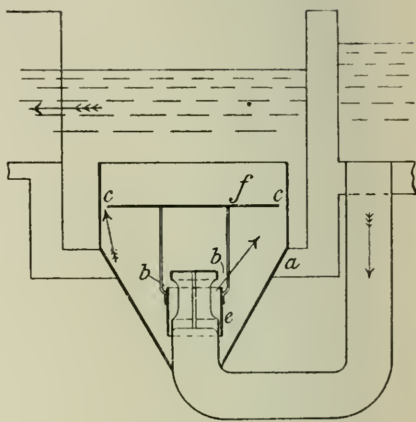


Fig. 15.

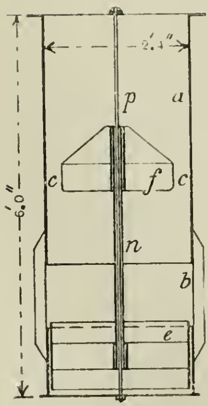


Fig. 16.

Module fixed in a Watercourse.

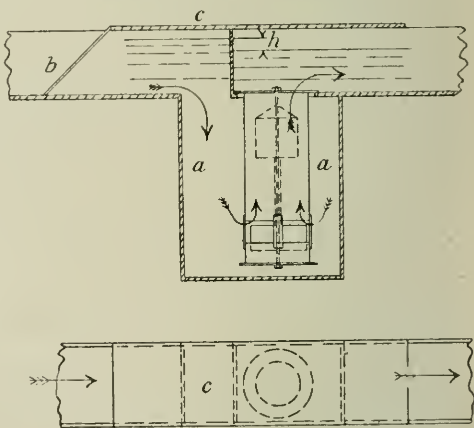


Fig. 17.—*Curves showing the Limits within which the Module* (Fig. 15) *operates.*

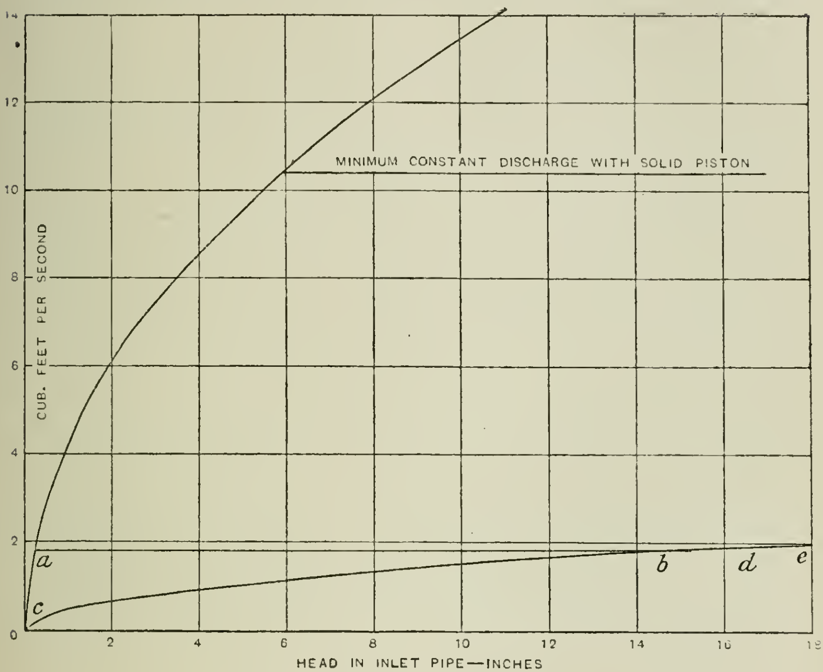
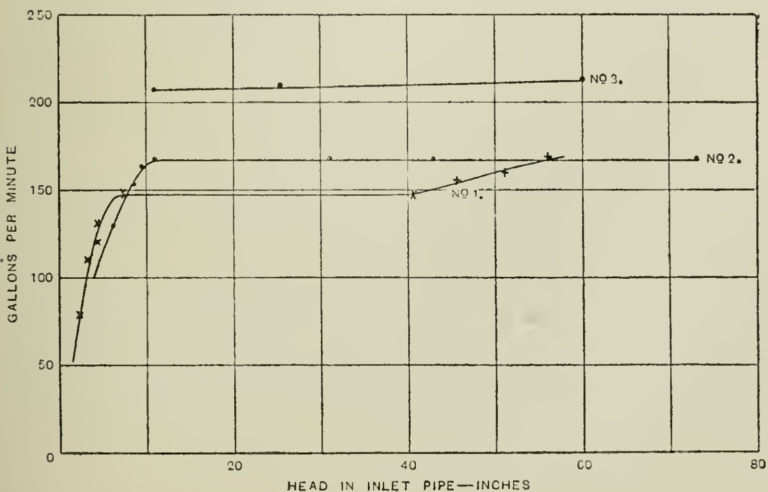


Fig. 18.—*Results of Tests with Solid Piston*, Fig. 16.



over, the minimum working head in that case being about 6 inches.

Fig. 16 shows how this module may be fixed in a watercourse. It is hung by the top flange in a timber or concrete box *a*, the arrows showing the direction of flow. The cover *c* protects it from damage, while the grating *b* keeps out the larger pieces of floating matter.

In Fig. 18 are shown the results of tests made on a small module of this type having a solid piston. The two lower curves show a perfectly uniform discharge at working heads above 7·5 inches and 11 inches. In test No. 2 the valve was slightly heavier than in test No. 1, and of a different shape; in No. 3 it was still heavier, and the centre guide was taken out.

The outer casing may be made of timber or concrete, and of a rectangular section, the only metal parts required being the float, valve, and centre guide-rod, and thus constructed it may be installed at a very moderate outlay. The upper part of the float is made conical in order that silt may not collect on it and alter the weight. Instead of the water flowing upwards, it may be made to flow in the reverse direction, and certain advantages may be obtained by this arrangement.

The design shown in Fig. 15 seems to possess more of the qualifications of a good module than almost any of the others hitherto described. The passages are large, and so long as there is no long grass in the water it will pass other floating matter of reasonable size without trouble. It is accurate over a wide range of changes in level, the loss of head is low, the rate of discharge may be readily altered, it is cheap, and the greater part may be built of materials obtained near the site. It may also be made secure against interference, and is easily portable, which is sometimes an important consideration. The chief defect is the existence of one moving part in its construction.

Since the discharge is determined wholly by the difference of pressure on the two sides of the piston or float, it is independent of the inlet and outlet levels. If the supply water is raised by any given amount, the discharge water-level may be raised by the

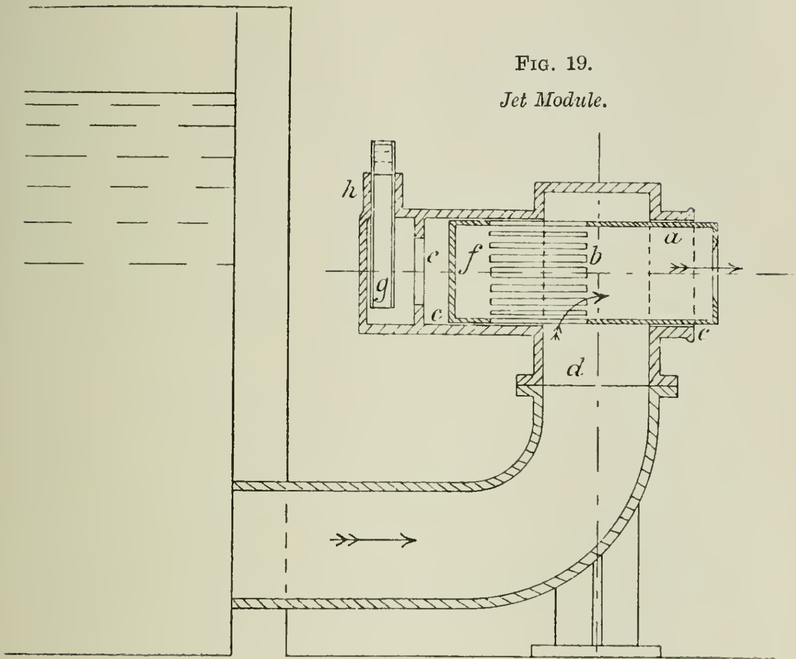


Fig. 19.

Jet Module.

Fig. 20.—*Results of Test on Jet Module*, Fig. 19.

same amount. Full advantage may therefore be taken of high water in the supply canal to irrigate the higher grounds which cannot be "commanded" when the supply is low.

If that part of the outer casing *a*, Fig. 15, in which the float travels is made conical and diverging upwards, then as the float moves towards the top the annular space or orifice *c* increases in area and the discharge becomes greater. This property may be made use of in order to abstract a definite proportion of the total volume from a stream in which the rate of flow varies. In this form the device may also be utilized to give, automatically, a greater discharge to consumers in proportion as the main supply increases.

Jet Module Figs. 19 and 20.—A nozzle *a* having ports *b* and a closed rear end *f* is free to move axially on bearings *cc* in a chamber which forms part of the supply pipe *d*. The rear bearing is extended to form a closed cylinder *e* in which the end *f* of the nozzle acts as a piston. A constant head is maintained in the cylinder, and when water passes through the nozzle the reaction of the jet forces the nozzle back, and cuts off the supply through the ports *b*, until the jet reaction and the pressure on the piston *f* balance each other. The rate of flow may be varied by altering the pressure in the cylinder *e*. There is always a slight leakage past the bearing *c*, and this overflows through the telescopic pipe *g*, which may be adjusted in height to give the necessary constant pressure in cylinder *e*, corresponding to any particular rate of flow. Fig. 20 shows the results of tests made on an apparatus of this description, the deviation from uniform flow being probably due to friction in the bearings at *c*.

Gibb's Module, Figs. 21 and 22.—This module, invented by Mr. A. S. Gibb of the Indian P.W.D., has no moving parts. Its operation is based on the fact that, when water flows in a curved path, the level rises at the outer circumference and sinks at the inner. In Gibb's module water flows through the circular steel casing *a* from the supply-pipe *c*. By means of properly shaped diaphragms *b*, above the waterway *d*, that portion of water which

Fig. 21.—*Module with no Moving Parts* (Gibb).

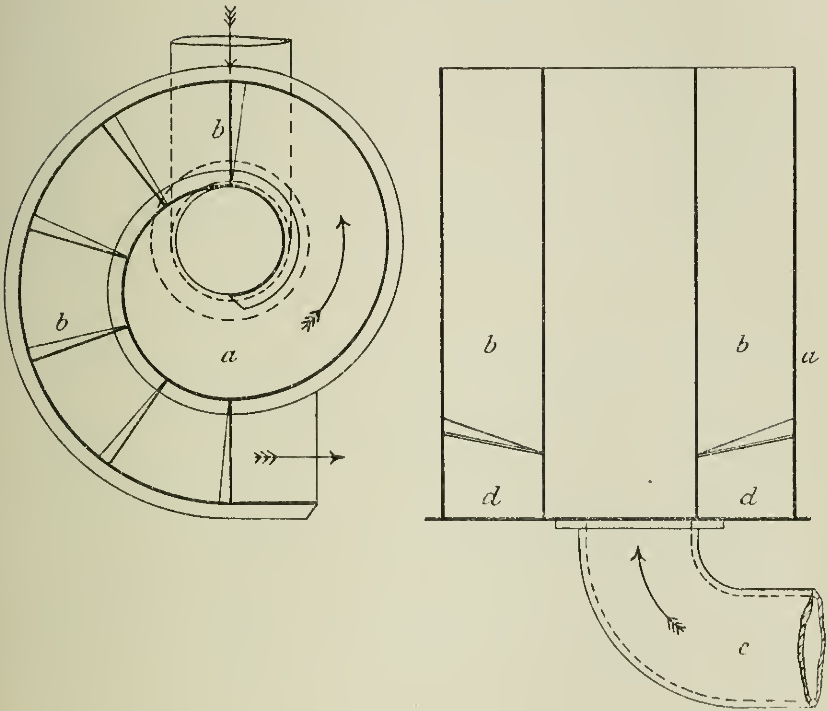
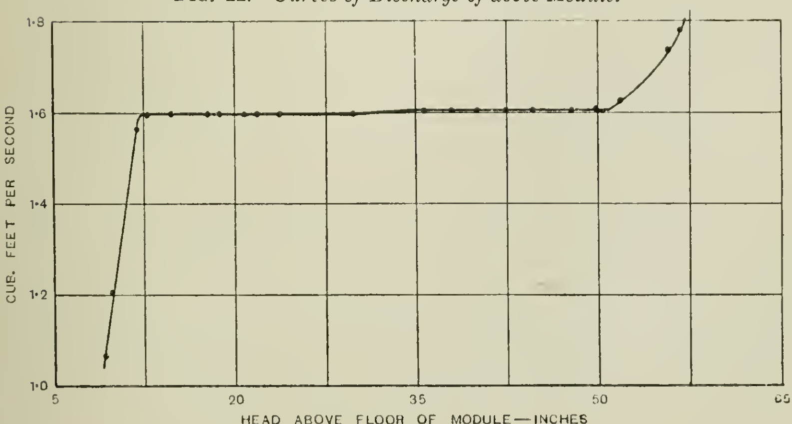


Fig. 22.—*Curves of Discharge of above Module.*



rises at the outer circumference is skimmed off and thrown over to the inner side, and in this operation its velocity head is completely destroyed. The casing *a* is open at the top, and when working, the loss in the successive compartments may be observed. This module is very ingenious and simple; there are no moving parts in its construction, and it works very efficiently, curves of discharge being shown in Fig. 22. It seems to be impossible to alter the rate of flow except by changing the dimensions of the waterway or by altering the number of diaphragms.

Kennedy's Module, Fig. 23.—This module was invented by Mr. R. C. Kennedy, late chief engineer of the Punjab Irrigation Service. It consists of a long tube *a*, divergent from the throat *b*, towards the outlet end *c*. The vertical pipe *d* communicates with the throat and is open at the top to the atmosphere. In order to explain the mode of operation, assume the water to stand at the same level in the supply and discharge channels and in the pipe *d*. As water is drawn off and the discharge goes on increasing, the level in *d* falls (according to the Venturi law) until, when it reaches H, the pressure in the throat is that of the atmosphere and the corresponding loss of head is *h*. The discharge is now taking place under the head h' into a region of atmospheric pressure in the throat, and the rate of flow is therefore determined by the head h', and cannot be increased by lowering the outlet level beyond the amount *h*. The apparatus is laid in the canal bank at such a level that it will discharge the correct quantity when the water-supply is at its normal level. If this level varies, the discharge will also vary, and a scale *s* on the vertical pipe *d* serves to indicate the rate of flow when the loss of head is equal to or greater than *h*.

If the top of the vertical pipe be closed, a partial vacuum forms in the throat and the discharge may be greatly increased beyond the rated quantity. In order to prevent consumers from taking advantage of this property, the makers sometimes close the top of that pipe and connect to it one end of a horizontal pipe *g*, the other end of which is perforated for a considerable length, and laid

Fig. 23.—*Module* (Kennedy).

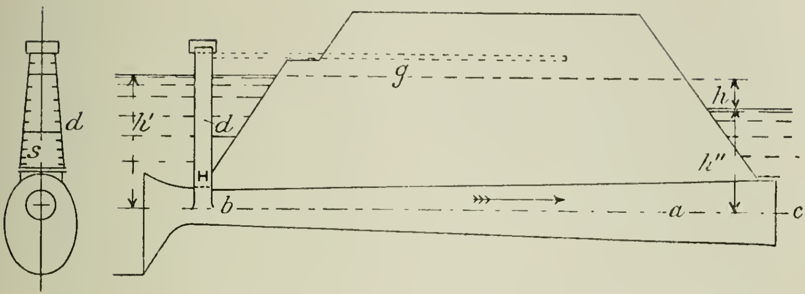


Fig. 24.

Diagram of Module similar to Fig. 23 *ensuring Constant Flow with Varying Head.*

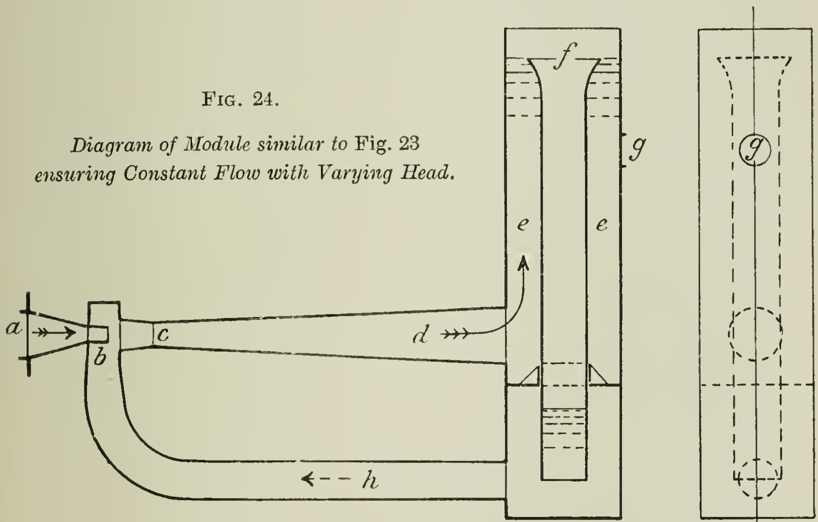
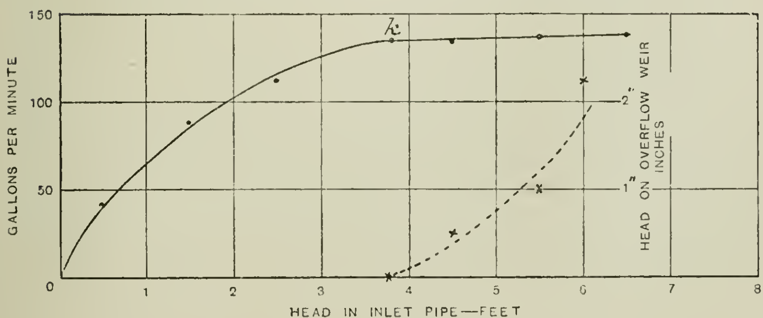


Fig. 25.—*Result of a Test on a Device similar to* Fig. 24.



in porous soil in the canal bank. The consumer cannot now reach the perforations, which are of sufficient area to draw through the soil all the air required to maintain atmospheric pressure in the throat.

Mr. Kennedy has invented several modules for use under different conditions. One, similar to that in Fig. 23, permits water to flow back from the outlet into the throat when the discharge through the Venturi tube exceeds a certain amount. An almost identical design, shown diagrammatically in Fig. 24, was prepared and tested by Mr. F. H. Bruges and the Author. Water from the supply-pipe *a* passes through the nozzle *b*, the throat *c*, and divergent pipe *d*, and rises in the chamber *e* until it reaches the top of the weir-pipe *f*. The discharge takes place from the orifice *g*, excess water flowing over the weir-pipe and back to the throat through the pipe *h*. Unlike the Kennedy module, Fig. 23, this one maintains the rate of flow constant with a varying inlet head. Fig. 25 shows the result of a test on a device of this description. It comes into operation at *k*, and the variation in discharge at higher heads is due to the overflow weir being too short. The lower curve shows the height of water above this weir.

Subdivision.—A method of water distribution which is still practised, and has been from an early date, is that of subdivision—that is to say, all the water in a stream is divided among a number of consumers in certain proportions. According to a very old method, the bed of the stream was made wide and shallow with flat bottom and vertical sides. At the end of this prepared section there was a sudden fall in the bed of a few inches, and when falling over the crest the water was parted in the proportions required by knife-edge and diverted where required. It is probable that this design, with suitable baffles and with the sides of the channel sloping outwards after the manner of a Cippoletti weir, would give good results, and that the discharge would be uniform all along the length of the crest, and therefore easily subdivided in any proportions.

In another method of subdivision the stream flows into a stilling

chamber provided with weirs or orifices of the correct dimensions to give to each consumer his allotted proportion. Cippoletti weirs should be used in preference to rectangular weirs, because in the former the discharge is proportional to the length of the crest, which is not the case with the latter; the crests should also be all at the same level. If orifices are used they should be made rectangular and all at the same level and of the same height—any difference between them being in length alone. The simplest way to subdivide a stream is to let each consumer have the whole discharge for a time proportionate to the quantity to which he is entitled. It is sometimes desired to abstract a definite proportion of the whole volume from a stream in which the flow may vary. The device shown in Fig. 15 (page 522), having a conical throat as described on page 526, may be used for this purpose.

Irrigation Meters.—So far as the Author is aware, little progress has been made in applying automatic recording meters to the supplies of individual consumers, except in Australia and to a small extent in North America and Italy. The Hill meter in California and the Grant-Mitchell meter in Australia are both for use in open channels and are very similar to one another. The water flows up, through, and over the top of a vertical pipe in which there is a wheel with angled vanes revolving about a vertical axis, or the water merely flows upwards through a horizontal submerged orifice in which the wheel revolves. In either case the revolutions of the wheel are proportional to the mean velocity of the water through the pipe or orifice, and the shaft extended upwards actuates a dial which records the quantity of water passed.

The Dethridge meter, also an Australian invention, and for use in open channels, is shown in Fig. 26 (page 532), and consists of a small water-wheel placed in a contracted part of the channel. The wheel revolves on a horizontal axis and actuates a recording dial through gearing. Fig. 27 gives the result of a test of a meter of this description along with a curve showing the loss of head.

Cheap forms of the Venturi meter are also used for irrigation work, and a very simple form of indicator for this meter is shown

in Fig. 28. An external pipe is carried from the upstream side of the main pipe to the throat of the Venturi tube, and in it a small meter is fixed. The pressure at *b* being higher than at *c*, water will flow into the throat through the small meter *a*, whose dial, suitably marked, will indicate the total flow in the main pipe. The curves show the result of tests of this apparatus, the diameter of the pipe and throat being respectively 9 inches and 3 inches. The upper curve is the result of two tests, one being made with an increasing

Irrigation Meters.

Fig. 26.—*Dethridge.* (Australia.)

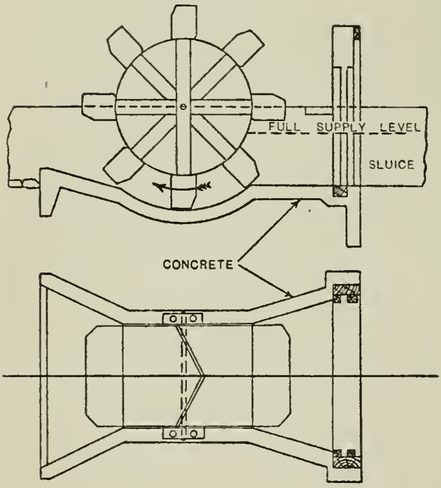
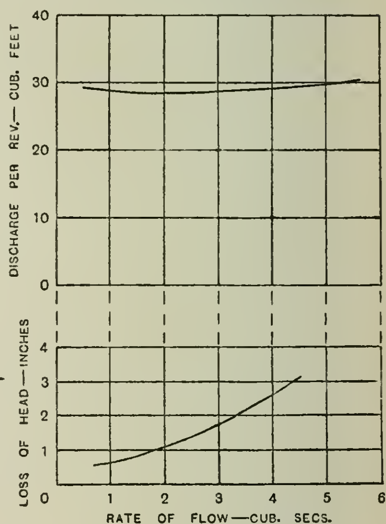


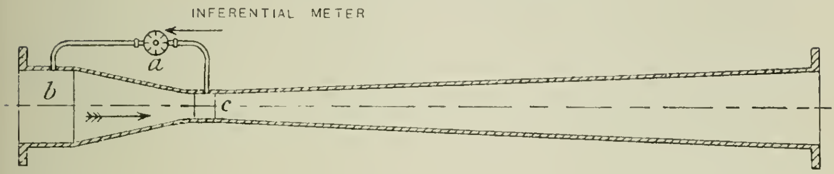
Fig. 27.—*Result of a Test on a Meter similar to* Fig. 26.



flow and the other with a diminishing flow. A Glenfield rotary meter was used, and the results of the two tests lie practically on the same straight line. The lower curves were plotted from tests taken with a different meter, but the readings taken with increasing and diminishing flow do not coincide. In all cases, however, the plotted results lie very nearly on straight lines, showing that the flow through a suitable small meter is very nearly proportional to the total flow in the main pipe.

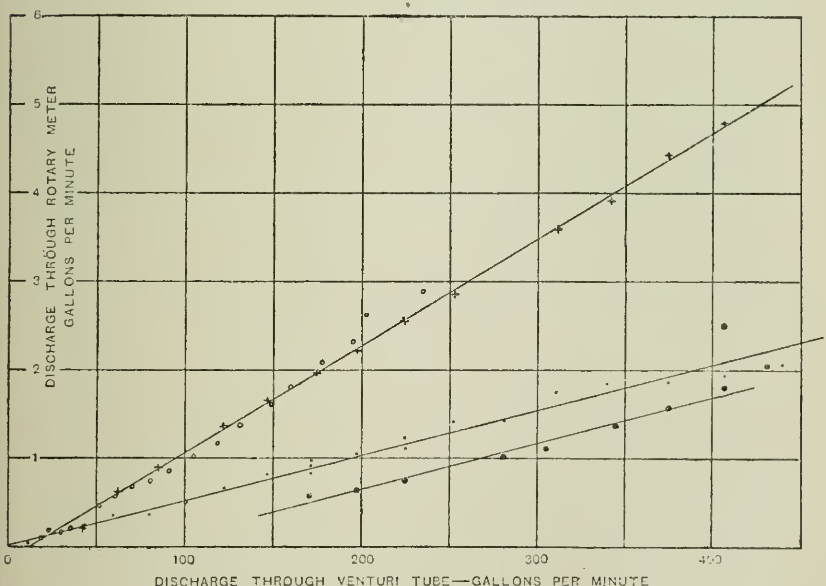
Water passing round a curve assumes free vortex flow in which there is a difference of pressure at the inner and outer walls of the channel. This difference of pressure may be utilized to indicate

Fig. 28.—*Venturi.* (Struben.)



Tests.

Diameters at "*b*" 9 inches, at *c* 3 inches.



the rate of flow in a pipe, but while actual tests have shown that a meter on this principle gives accurate results, it offers no advantages over others already in use.

Clock and Cam Meters.—The most familiar example of the application of these meters is in connexion with the Venturi tube, but they are also used to a great extent to measure the discharge over weirs through orifices or along channels. The integrating mechanism is driven by a powerful clock, while the rate of integration is controlled by a cam, shaped according to the formula applicable to the flow in each particular case. The accuracy of these devices depends, among other factors, on the time-keeping qualities of the clock, on the degree of correctness of the formula used in shaping the cam, and on the absence of friction in the cam and the mechanism which actuates it. These meters are equally applicable to the measurement of small and large flows, and in conjunction with an accurately constructed Venturi tube, weir or channel, they offer, in fact, the only automatic means for the measurement of large volumes of water.

It cannot be said of these meters that they are satisfactory for general irrigation purposes, and on the whole they are not regarded with much favour. By far the greater number of "metered" supplies are measured by passing the water under constant head through orifices, the area of which may be adjusted by hand. A device similar to that shown in Fig. 1 (page 512), having the orifice of a narrow rectangular form, and with a shutter sliding horizontally along its length, is used to fix the rate of discharge. The canal officer regulates the head in chamber *c* in the manner already described, and if necessary he also alters the length of the orifice and notes the time for each different rate of flow, which is assumed to be proportional to the horizontal length of the orifice. During his absence both the sluice and shutter are locked in position and cannot be interfered with. In the United States an arrangement of this kind is in very general use. The orifice is in a vertical plane and has sharp edges and complete contraction. It may be of any length, and the head is kept constant at 6 inches above its centre. Under these conditions, openings 1 inch, 2 inches, 3 inches, etc., long will discharge 1, 2, 3, etc., "Miner's Inches." Except for the fact that it varies in different States, the Miner's Inch is a satisfactory unit for

irrigation work, and anyone may measure it and its multiples with an ordinary measuring rule. For this reason it is widely used in North America, and consumers get so many Miner's Inches for a day or a week or any length of time as may be arranged. Other devices to which this principle may be applied are: Foote's module, Fig. 4 (page 514), Harrison's weir, Fig. 3 (page 512), and the movable orifice shown in Fig. 2 (page 512).

Instead of orifices, Cippoletti weirs may be used having the length adjustable, the discharge in this case being proportional to the length of crest.

In all those devices there is a certain amount of loss of head, without which it is apparently impossible to measure water accurately and continuously. Where there is no head available to operate a meter of any kind, standard channels have been proposed for the measurement of supplies to each purchaser. Such channels would be carefully calibrated and the discharge determined according to the depth. At any future time the rate of flow may be ascertained by observing the depth and referring to the original test results for the corresponding discharge. Should the water in these standard sections be subject to back-water effects from the operation of sluices on the downstream side, the original test results could not be made use of. In that case the area of the stream must be found and the velocity observed by current meter or otherwise, and from these data the discharge may be calculated.

Nearly all the devices which have been described have been used more or less successfully for measuring water or for maintaining a constant rate of flow, but a large proportion of them, owing to comparatively high cost or for other reasons, are unsuitable for irrigation purposes where the conditions to be fulfilled are of such a conflicting nature. In many districts supplies are still regulated by men engaged for that purpose, a system which has existed for centuries and apparently still gives a fair amount of satisfaction to the majority of people who buy or sell water for irrigation purposes.

The Author is greatly indebted to the late Mr. John Barr, of Messrs. Glenfield and Kennedy, Ltd., Kilmarnock, for suggestions and much information regarding some of the devices mentioned in

the Paper. The meter described on page 532, and shown in Fig. 28, is the invention of Mr. Arthur Struben of Cape Town. Many of the devices have been already described in engineering periodicals, a list of which is given in the Appendix.

The Paper is illustrated by 28 Figs. in the letterpress, and is accompanied by an Appendix.

APPENDIX.

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Discussion.

Mr. John Ashford wrote that it was pointed out in the Paper that for many years engineers had endeavoured to produce a module that would ensure the equitable distribution of water for irrigation and other purposes. The difficulty experienced in producing a satisfactory contrivance was due to the complex conditions which were experienced. These conditions did not seem to have been very closely brought out in the Paper, particularly so far as the use of modules applied to irrigation purposes. It should be clearly understood that a module was not a meter, but rather an arrangement which would allow water to pass from one channel to another in equitable proportion.

A system of irrigation channels might be likened to a tree in which the trunk would represent the main canal; the main branches of the tree represented what were also called the main branches of the canal, and the smaller branches the major and minor distributaries which ultimately led to the farmer's fields as the branches and twigs led to the leaves. The water admitted to the main canal must be in such quantity as would be sufficient to supply water to all the ground embraced by the system, but each field only needed water occasionally, and the problem of distribution was to supply a satisfactory quantity of water to each field without excess and at proper intervals of time. To effect this distribution the various channels must be opened in turn, and a correct volume of water admitted thereto for the area to be irrigated. In times of scarcity when water was somewhat inadequate, it was desirable that it should be distributed equitably, so that each farmer might get a fair proportion of that which was available.

The problem was naturally somewhat complex under the best of conditions. It would, of course, be simplified if the water were in excess, so that places could be provided near the tail end of the distributaries to pass that excess to waste, but in countries where irrigation was necessary, water was too valuable to waste in this way, so the control must be sufficiently close to utilize the water

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entirely without waste, and in such manner that the maximum duty might be obtained. The problem would not be so difficult if the available water were clean, and if the condition of the channels remained constant, and if the users were honest people satisfied in receiving their correct allotment. With such ideal conditions the flow of water in each channel would be at a correct level, and a simple orifice of suitable area placed at a correct depth below the surface of the water would ensure the distribution required, but all those ideal conditions were not found in fact.

Water taken from rivers and most other sources of supply for irrigation purposes contained both mineral and vegetable matter in suspense, varying in quantity at different seasons of the year. The mineral matter was usually called silt. Water in motion was capable of carrying a proportion of silt which depended upon its rate of motion, and when it flowed down channels, the width and depth of the channels affected the proportion. The grade of silt carried, that is to say, its degree of coarseness, also varied in like manner. Should a stream of water change its velocity, it would tend either to pick up or deposit silt according as the change might be positive or negative.

One problem of the irrigation engineer was to so arrange his distribution channels and the flow of water therein, that the water was delivered on to the fields with the same silt content as it received from the source of supply. Truly a difficult problem, as would be acknowledged when it was borne in mind that the amount of silt contained in the water at the source of supply was variable. The countries where irrigation was necessary were mostly tropical or subtropical, and there, in the presence of sufficient moisture, vegetation grew with great rapidity, and it required constant care to keep the channels from such obstruction, in fact it might be said to be impossible to do so absolutely.

Where a farmer's crops depended upon irrigation water, he needed to be an unusually honest man if he was to be content with his allotment, and not to attempt to increase his supply by some form of interference with the arrangements, particularly in times of drought in a country like India, where men had been known to

commit serious crimes over the distribution of water and the interference therewith. Many a breach had been cut in a canal bank to secure an adequate flooding of land, regardless of the shortage that would result to other farmers, and it was a common occurrence to introduce an obstruction in a channel to head up the water, and so force an additional quantity through the orifice. Should an excess quantity of water be passed into a distributary either by intent or accident, it was desirable, in order to avoid breaches in the banks, that when the water rose to excess level it should pass through the distributing device in such manner that all parties benefited by the excess to an equal extent. The lot of a farmer, whose land was situated near the tail end of the distributary, was indeed a sad one when his supply was dependent upon the integrity of all those users who drew their supplies from the same channel nearer the head.

An ideal module must so control the water that, in spite of the variable conditions, all would be equitably served. The Author of the Paper had detailed a number of devices which had been tried, and doubtless many of them had proved successful where the conditions had suited them, yet few of them had been found entirely satisfactory for irrigation. Where silt was carried in the water, the heavier particles would naturally move near the bottom of the stream, thus it was impossible to arrange for the module to draw its supplies from near the surface, for it would then take less than its share of silt, with the result that further down stream the water would be more heavily charged and would deposit silt to the obstruction of the channel. The opening of the module, accordingly, should be at or near the bed level, and should be of such shape that it extended towards the surface sufficiently to draw off an even proportion of the silt. Inasmuch as it was practically impossible to maintain a constant condition of channel, the module should give a constant discharge with a certain fluctuation of watel level, but when a certain maximum was reached, it should increase its discharge more or less proportionately to the excess of head above the required maximum.

It was obvious that the construction of the module should be

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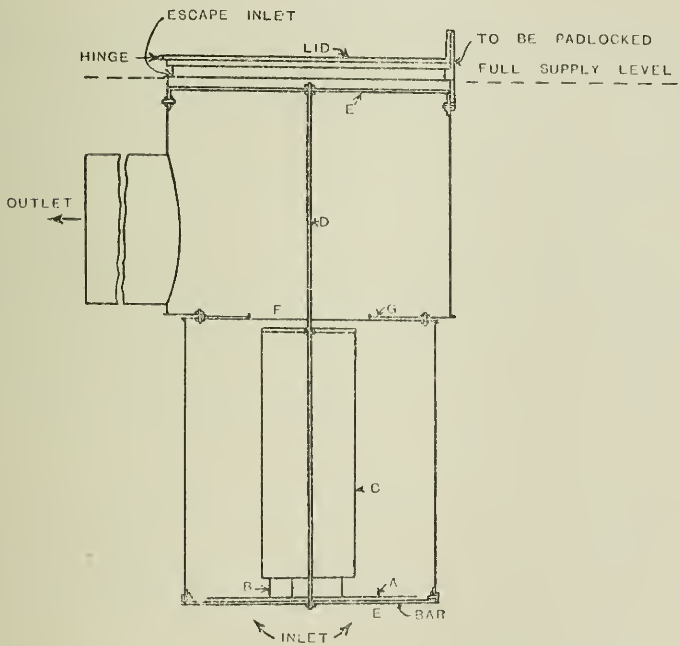
such that floating vegetation should not choke it or in any way interefere with its successful working, and it should be impossible for the farmer to tamper with it and so disturb the distribution. Those modules which had movable parts, or depended upon any mechanical arrangement, were liable to get out of order by rusting or corrosion or to be thrown out of adjustment by the cultivators, to get excess water. It might therefore be said that the ideal module had no moving parts. Two of the modules mentioned in the Paper fulfilled this condition, namely, Kennedy's and Gibb's. That the former might control the volume of water passing through it, the admission of air at the throat was necessary, and should the air-passage be closed, the device ceased to be a module. The originator of the type, and those who manufactured it, had endeavoured so to make the arrangement that the air-inlet could not be tampered with. It needed, however, a very clever arrangement that would "best" the cultivator in his effort to check the modulating effect. It would therefore appear that the Gibb type was least liable to such interference.

A Paper on this subject was scarcely complete without a reference to Wilkins' module and also to Kennedy's module gate. The Wilkins' design, an illustration of which was shown in Fig. 29, was a modification of the piston type of module. Referring thereto, it would be seen that within a suitably shaped body there was a piston-plate A, surmounted by a tube C, the two being connected by three or four bars B, which left an opening above the plate into the tube. The piston-plate was a little smaller than the body of the module, a space being left for the passage of water between the plate and the body, and the water passing to the upper side of the piston had entry to the interior of the tube C, and it might also rise about its exterior. The water pressure acting beneath the piston caused the latter to rise, so that the upper end of the tube C passed through a hole F, in a diaphragm plate G. The hole F was larger than the tube C, so that a portion of the water rising outside the tube might pass forward to the outlet. The remainder of the water must pass up the interior of the tube and overflow at the upper end. It was obvious that the

pressure of the water below the piston must ultimately be balanced by the column of water above it, plus the weight of the movable part, and that an adjustment of this weight or of the size of the piston would affect the rate of discharge. This module was said to give a very close regulation of discharge with a very small loss of head when in good working condition. The rod D in the illustration supported by the bars EE served to guide the piston and tube in a central position.

Fig. 29.—*Module* (Wilkins).



The Kennedy module gate was designed for service at the heads of distributing branches to control the quantity, automatically, that should be admitted. The gate was swung upon trunnions placed near its upper edge, and when it opened it must move against the stream, the stream thus constantly tending to close it. The floor of the chamber in which the gate was placed was so curved that the available opening for the passage of water as the

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gate opened was greater than if the floor were flat. The side frames of the gate extended above the trunnions to act as levers, to which a counterpoise was attached by links. The counterpoise was arranged that it might move by a rolling action along curved guides of ogee shape, so formed that the correct amount of force was exerted upon the levers of the gate to balance the stream pressure at the correct positions required for the discharge of the right amount of water at all heads within its working range.

Mr. Walter Clemence wrote that the author had referred on page 511 to the importance of the question of the reduction of friction in the case of modules where moving parts existed. In the opinion of the writer this question involved practical difficulties, which rendered all modules with moving parts practically non-automatic.

A good type of controller for slow sand-filters was that known as the "Didelon" regulator which was largely used on the Continent. It combined the types of modules illustrated by the Author in Figs. 8 and 11 (pages 518 and 520), and was quite reliable in maintaining a constant flow from sand-filters under varying loss of head if suitable counterweights were provided. A description of this regulator would be found in the Proceedings of the Institution for 1909 (page 65).

The circular floating weir, Fig. 6 (page 516), had been used by the writer for regulating sand-filters, but the sliding-pipe gave trouble and it was found impossible to prevent the leaking referred to by the Author (page 517), while maintaining freedom of movement of the floating weir. A modification of this valve had given good results at Port Said. In place of the sliding-pipe a double-jointed floating arm was adopted, to which the short vertical pipe, marked *a* on the Author's diagram, was connected.

A module of the type illustrated in Fig. 13 (page 522) had been designed by Mr. C. F. Wilkins (page 541) and was largely used in irrigation works in India. A similar module controlled by counterweights had recently been installed at Lucknow for

regulating the delivery from slow sand-filters. It had given good results but was expensive to install. A description of it was given in the Report of the All India Sanitary Conference held at Lucknow 1914, vol. v. page 114. This Report was issued as a Supplement to the Indian Journal of Medical Research.

The movements of the working parts of modules designed to secure a constant rate of flow were necessarily slow, and in the writer's experience "limpets" of iron and other deposits quickly formed on them, and became a source of trouble unless the apparatus received frequent attention and cleaning. In the case of properly balanced modules for controlling filter-beds, this difficulty could generally be overcome, as they were usually under constant supervision, and the moving parts could be easily and frequently cleaned. But such supervision was practically impossible in the case of modules used for controlling the inlets to large covered reservoirs, where the apparatus was drowned out and rendered inaccessible except at long intervals. Great care was necessary in the selection of types suitable for working under such conditions, and in the writer's opinion the value of a most interesting Paper would be enhanced if the Author would quote instances of difficulties occurring in the use of the various types of modules described in the Paper, and of the means taken to overcome them.

Mr. H. H. Dare (Commissioner for Water Conservation, New South Wales) wrote that the Murrumbidgee Irrigation Scheme now being developed in New South Wales would, it was anticipated, ultimately provide for the irrigation of about 200,000 acres. The area at present irrigated was about 32,000 acres. The supply was drawn from a canal of 1,000 cubic feet per second capacity, the length of which now in use was 31 miles from the point where water was first drawn off. There were also two main branches, of capacity of about 400 and 350 cubic feet per second respectively. It would be necessary to enlarge and extend the main canal before the ultimate area could be served. At present, water was drawn off from the main canal, and two main branches at fifty-nine offtakes into lateral channels of capacity from 5 to 100 cubic feet per second.

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Lifting gates, controlled by screw-gear, were used at the points of draw-off to the larger laterals. In some of the smaller laterals pipe-outlets were used.

The number of farms watered from each lateral varied from 1 to 100, water being available every fifteen days during the irrigating season, or oftener in special cases. To facilitate watering, dropboard checks had been constructed at intervals along the lateral channels. At each farm the water was drawn from the lateral channel through a Dethridge meter outlet. The farm watering was controlled by a staff of water bailiffs, much of whose time was lost owing to the necessity for altering the level of the gates at the main offtakes. This was due to the fact that neither the level of the water in the main channels nor rate at which the farms were watered was constant. If a suitable module could be substituted for the offtake gates, it would be very desirable. Such a module should, at moderate cost, not only discharge a fixed quantity of water under a variable head, but should be one in which the quantity to be discharged could also be varied from time to time. As pointed out by the Author of the Paper, it was doubtful whether any such ideal module had yet been devised to meet the variable conditions of irrigation work.

On the Murrumbidgee Areas the natural fall of the country was only about 18 inches per mile, and any overfall device was out of the question on account of the loss of head. A module of the Gibb or other type, involving small loss of head, would be of service, in the absence of the ideal module, provided that the cost of installing was not high. When the late Mr. John Barr was in Australia some two years ago, the question of modules was discussed with him, with the result that Messrs. Glenfield and Kennedy had recently devised a regulating valve (not described in the Paper) to be placed in and worked by a float in the lateral channel. The object of this valve was to pass a constant stream, irrespective of the level of the main canal. The valve consisted of a cast-iron inner and a galvanized iron outer casing, both perforated with six horizontal rows of holes. The outer casing was operated by the float, and slid over the inner casing, so that when the float was at

its lowest position the holes were opposite to each other, and, as the water level rose, these were gradually shut off. A valve of ten cusecs estimated capacity of this type had been installed on the Murrumbidgee Areas, and would be tested at the beginning of next watering season.

With regard to irrigation meters, a few of the Grant-Mitchell type were in use in New South Wales, but Dethridge meters had been universally adopted on the Murrumbidgee Area, where about 1,600 had been installed. A few of these were of small size, 4 feet $1\frac{1}{2}$ inches diameter over vanes, but the standard size used was the same as installed by the inventor, Mr. J. S. Dethridge, in Victoria, namely, drum 2 feet 6 inches wide, 3 feet 4 inches diameter, and 5 feet diameter over the vanes. Drum and vanes were of No. 14 gauge sheet steel, with hard-wood spokes, and 1 inch galvanized iron pipe-axle, at one end of which was a Veeder cyclometer, which registered 0·01 for every 15 revolutions of the meter-wheel. This figure represented $\frac{1}{100}$ acre foot. The meter-wheel worked in a box of concrete 4 inches thick.

A recent bulletin, issued by the University of California Experiment Station,* referred to tests of the Dethridge meter as follows:—

> "The tests of this device made at Davis showed the meter to be quite accurate under constant ditch conditions between rates of flow of 1 to 3·5 cubic feet per second . . . The Dethridge meter of this size is adapted for accurate measurement of streams varying from 1 to 3 or 4 cubic feet per second; in Australia it is considered satisfactory up to 5 cubic feet per second."

The curves representing results of the Californian tests showed a loss of head, for discharge 4 cubic feet per second, of 0·32 ft. where there was a clear fall from the meter to waste channel, and 0·20 ft. when tested with water over the lower sill, similar to ordinary ditch conditions. The curve shown in the Paper was

* "Some Measuring Devices used in the Delivery of Irrigation Water—Bulletin No. 247, University of California Publications."

(Mr. H. H. Dare.)
presumably that prepared by Mr. Dethridge from tests made under usual conditions of working, and this lay between these.

The normal cost of the standard size of Dethridge meter wheels as manufactured on the Murrumbidgee Area was about £2 8*s*., and the cost of each outlet complete about £12. It should be noted that on this Area the cost of concrete materials was high. With proper attention to bearings and coating of steel work, these meters had been found very satisfactory.

The Venturi meter had not been used on irrigation works in New South Wales, nor had any of the modules described in the Paper, which was one of great interest to irrigation engineers.

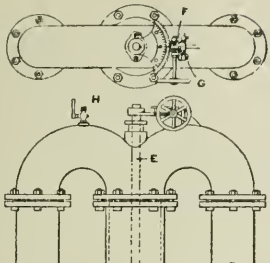
Mr. L. Vincent Greaves wrote that he wished to draw attention to an apparatus devised by Mr. W. M. Langford for regulating the flow from slow sand-filters at waterworks, but which, however, was equally applicable for irrigation purposes, by modifying the design to suit the smaller variation in water-levels. This was similar in type to Fig. 8 (page 518), but had the additional advantage that the rate of discharge might be readily altered as desired, and the rate of flow might be observed at a glance.

A, Fig. 30, was a galvanized-iron float which carried a three-legged siphon B, the long—or discharge—leg of which projected downward into the stand-pipe C. Thus the outlet end of the siphon was always kept the same fixed depth below the water surface. D was a gun-metal regulating cock which might be opened or closed at will by means of the spindle E, actuated by the worm and worm-wheel F. The spindle E carried at its upper end a quadrant with graduated index plate, which by its position in relation to the fixed pointer G indicated the degree of opening of the regulator-cock, and thus the rate at which water was passing through the apparatus.

The middle leg of the siphon was quite free in the stand-pipe which served as its guide—an important factor which would readily be appreciated when compared with the effect of friction on the telescopic pattern with submerged joint.

The accuracy of the apparatus was still further increased by the

Fig. 30.—*Apparatus for regulating flow of slow sand-filter* (Langford).



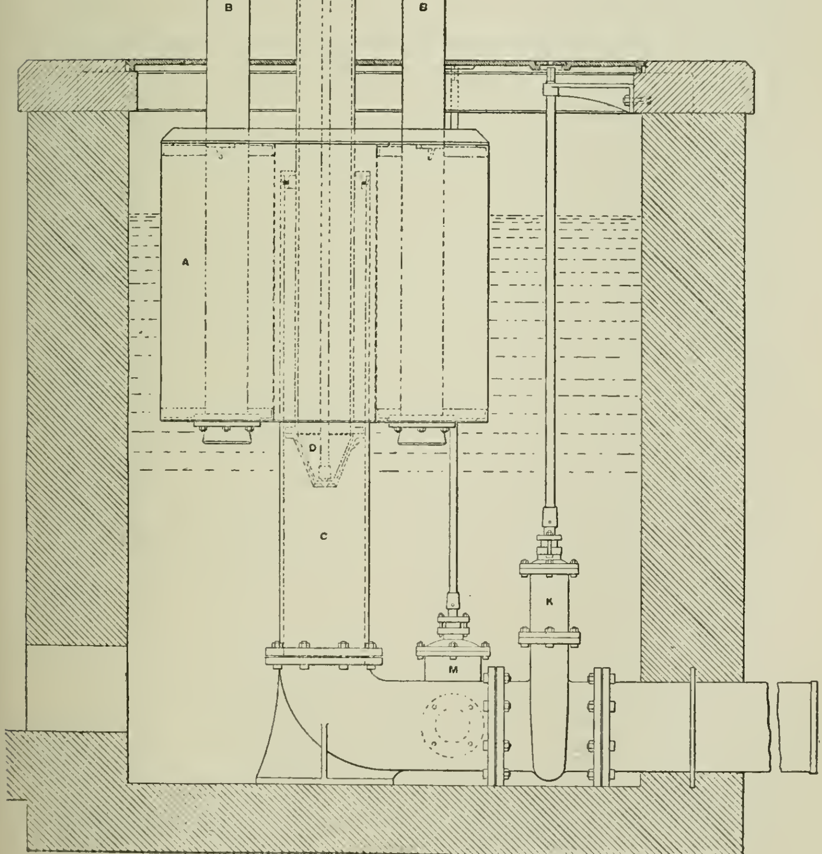
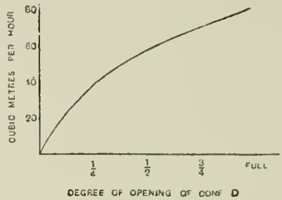


Fig. 31.—*Result of test on Regulator, with various degrees of opening regulator-cock.*



(Mr. L. Vincent Greaves.)
relatively greater head under which it operated. Thus, an increase of submergence of, say, $\frac{3}{16}$ inch would have little or no appreciable effect on the rate of flow, but in other forms of automatic regulators in which the depth of water over the lip was only 2 or 3 inches, an important change in the rate would be introduced. To charge the apparatus, the sluice-valve K was closed and that at M opened. The air was then withdrawn from the siphon through an air-cock H at the summit, by means of a small hand-pump, or, when two or more regulators were situated near together, the air-cock of the siphon to be charged might be connected with that of its operating neighbour by means of a rubber pipe. The sluice-valve M was then closed, and on K being opened the siphon came into action. The working of the apparatus could be suspended at any time by merely closing the valve K, the apparatus then remaining charged ready for immediate use. The alteration in the rate of flow could be adjusted as gradually as desired whilst the apparatus was at work.

A similar device was adopted in an installation of three regulators at Galatz Waterworks, Roumania, the bore of the middle leg (that is, nominal size) being 5 inches. The diagram on Fig. 31 showed the result of a test made on one of these regulators with various degrees of opening of the regulator-cock. The output was variable, from zero to a maximum of 74 cubic metres of water per hour each, which is equivalent to 16,280 gallons each per hour.

As regards accuracy, this depended upon the care with which the apparatus was first calibrated. From a second test, however, of the above three regulators, made about a year after they had been installed, the discrepancies were No. 1, 0·354 per cent.; No. 2, 1·27 per cent.; and No. 3, 1·56 per cent.

Mr. D. C. Leitch wrote that he thought the use of a submerged orifice in connexion with the Italian module, which was otherwise desirable, appeared to be free from the objections cited by the Author (page 513), so long as provision was made to keep the down-stream or tail-water level constant. There did not appear to be any difficulty in doing this, either by allowing the outflow from

the orifice to discharge over a weir at a level slightly above it, or by forming the orifice with a quadrant pipe bend, the outer end turned upwards and bell-mouthed. Either of these arrangements would give a head over the orifice equal to the full difference of level between the water in the chamber and downstream. As the Author remarked (page 513), this should be as great as possible, to ensure uniformity of discharge. In Fig. 1 only part of the available head was utilized. It was suggested that the difficulty referred to by the Author on page 513, of the silting up of the shutter chamber or pit shown in Fig. 2, might be obviated by using an orifice placed excentrically in a circular shutter capable of rotation about its centre; a scale on the edge of the shutter and a mark on the frame indicating the depth of the orifice in different positions of the shutter.

The Author remarked (page 517) that the discharge from a floating orifice on a swivel joint, Fig. 7, increased slightly as the lever fell. This occurred if at low levels the proportion of the weight of the arm borne by the float increased. The enlargement of the floats was no doubt a partial remedy, but a more effective one was to attach the floats to the arm near the centre of its length.

The loss of head in the Spanish module was not necessarily considerable, as stated by the Author (page 518), though no doubt the particular arrangement, shown in Fig. 10, had this defect.

But, so long as the tail-water or down-stream level was kept constant, the loss of head need not be greater than in the other modules of the adjustable orifice type (page 522), and with a properly proportioned plug there seemed no reason to doubt that a uniform discharge could be maintained through a considerable range of head-water level.

Mr. Struben's ingenious substitution of a small inferential meter for the Venturi recorder was full of interest, but there seemed to be room for doubt as to the accuracy of the results. Obviously, the insertion of a by-pass between the entrance and throat of the Venturi meter introduced an element of error, proportional to the volume of water abstracted from the Venturi tube at its entrance, and returned to it at its throat. To minimize

(Mr. D. C. Leitch.)
this source of error, a very small by-pass must be used. But in such a by-pass, the critical velocity of flow might easily be reached with a considerable discharge through the main pipe.

Below the critical point the loss of head varied as the velocity; this point was known to be higher, other conditions being equal, with an increasing than with a decreasing flow. This variation in the critical velocity formed a source of error for which it was not easy to suggest a remedy; it might explain the discrepancy in one of the tests, the lower one, shown in diagram, Fig. 28 (page 533).

The use of a by-pass of moderate size in which the rate of flow was reduced by a diaphragm with small hole, as suggested by M. Dejust (*Comptes Rendus*, vol. 151), together with the use of a positive or semi-positive meter, might give more accurate results. It would be of interest to know how the discharges through the Venturi tube shown on diagram, Fig. 28, were ascertained. If an ordinary Venturi recorder had been used, the readings would only be accurate so long as the by-pass was kept closed; nor was it certain that the difference between readings taken with by-pass open and by-pass closed, would correctly represent the actual facts.

The Author's remarks (page 535), as to the use of standard channels, appeared to require some further explanation. The flow of water in a channel could not be measured without some loss of head; it did not seem certain that less head was lost in this way than in some of the other devices referred to in the Paper. A submerged orifice would probably have given better results in this respect, and would moreover have had the advantage referred to by the Author on page 513, that the discharge varied as $\sqrt{h}$, where h could be easily and accurately measured. In a channel a very small loss of head would have been less readily ascertained.

The Paper contained in a compendious form much interesting and valuable matter.

Mr. William Paterson wrote that the Paper gave a most useful analytical review of methods for controlling the flow of liquids, a fundamental problem of considerable difficulty. The

Author stated that in waterworks the conditions to be fulfilled by a controller were less exacting than in irrigation. While that might be so with reference to slow sand-filters, where the head was more or less constant, varying only a few feet per month, the requirements to be fulfilled by a controller for rapid filters were not easily met, as the head might vary 12 feet in as many hours; and the controller must be "dead-beat." Momentary irregularities, that would be immaterial in irrigation works, were detrimental to the filtration results, and might lead to the rupture of the filtering film.

The most convenient method of applying control to rapid filters was by automatically keeping the head constant over a discharge weir or orifice, but it was obvious that to maintain a uniform rate of flow while the discharge pressure varied greatly, a considerable movement of the valve was essential. This, however, was only obtained by a variation of head over the discharge weir or orifice, occasioned by a variation in the rate of discharge—the very condition the controller was installed to obviate.

The Author indicated that this error could be minimized by having a valve which "must be capable of opening through its full extent with a small travel of float." Unfortunately, such a valve was at once delicate and precipitate in its action. A small total float movement, even with a large float, implied minute operating forces, which were easily negatived by frictional resistances. Further, slight movements of a large ported valve gave great variations in the rate of discharge.

It seemed essential to satisfactory working that:—

(1) The valve must have a long stroke, giving a graduated opening to suit widely varying pressures.

(2) The control float should have a considerable range of movements, otherwise a slight resistance to movement might permit considerable variations in the rate of discharge.

(3) The large movement of control valve and float must be obtained with no appreciable variation in the head over the discharge weir or orifice.

(Mr. William Paterson.)

The writer had endeavoured to secure these requirements by arranging a float in a chamber into which a small proportion of the discharge overflowed when the critical head over the weir or discharge orifice was reached; this inflow being then balanced by an outflow. Obviously an inappreciable increase or diminution of the head over the discharge orifice resulted in the increase or cessation of the inflow into the float-chamber, and consequently in the closing or opening of the control-valve. Thus, under all variations of pressure, practically a constant head was maintained over the discharge weir or orifice. The float had a long stroke, and operated a valve with graduated ports to suit the supply pressure.

Fig. 32.

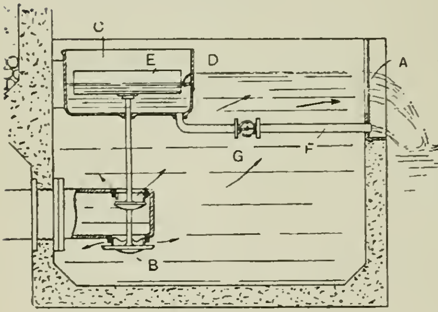
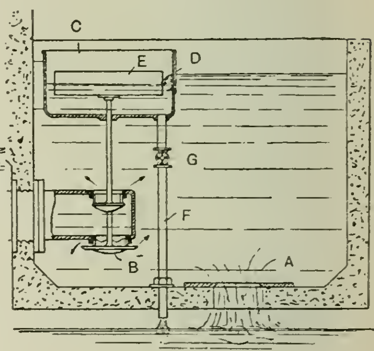


Fig. 33.



Figs. 32 and 33 showed the arrangement for maintaining a constant head over a weir and discharge orifice, respectively.

In Fig. 32, the outlet chamber was fitted with a discharge weir A, and discharge controlling-valve B. The float chamber C had an inlet weir D situated at the precise level at which it was required to keep the water in the discharge chamber in order to obtain a predetermined uniform rate of discharge. At this rate of discharge, a film of water overflowed into the float-chamber C in which was situated the float E controlling the discharge regulating-valve. This inflow of water was balanced at the normal rate of discharge by an outflow through an outlet pipe F, capable of adjustment by the valve G. The slightest diminution in the rate of discharge cut

off the fractional overflow into the float-chamber C, with the result that the water-level was lowered by discharge through the outlet pipe F, the float fell, opened the balanced control-valve B, and the rate of discharge was increased. The opposite effect was obtained when the rate of discharge increased above the normal.

It would be obvious that with this arrangement, a large movement of the float and valve was obtained with the minutest variations in the level of water in the discharge chamber. By suitable means the level and width of the inlet weir to the float chamber might be adjusted, so that the desired rate of discharge and sensitiveness of response might be varied.

Fig. 33 illustrated the application of the same device to the control of discharge through a submerged orifice.

Mr. Hugh Munro wrote, in reply to the Communications, that in the construction of modules it was of great advantage to adopt a simple form of outlet, for which an accurate formula had already been established by careful experiment, as in the case of weirs and circular orifices; otherwise it became necessary to calibrate the apparatus—an operation which added considerably to the cost. Such an outlet should be made exactly similar in form to the experimental one, and it should be used under the same conditions—otherwise accurate measurement could not be expected of it. The Author had seen, on more than one occasion, Francis weirs fixed with the bevelled side upstream, or with the approach channel of too small area—conditions which increased the rate of flow over that found by the formula.

Mr. Ashford and Mr. Dare gave some very interesting general information about the wider aspects of irrigation practice. With regard to Wilkins' module, Fig. 29 (page 541), described by Mr. Ashford, it was not clear how it maintained a constant rate of flow, except under small variations of head. The discharge was made up of two streams, one of which passed through the vertical tube C, and flowed over the top apparently under atmospheric pressure, and another which flowed through the annular orifice between the plate G and tube C. The discharges through these two passages

(Mr. Hugh Munro.)
varied as the position of the piston A and tube C varied, but the sum of the two must remain constant.

The difficulties experienced by Mr. Dare in controlling the discharge from the main canal to the laterals could be overcome by the use of suitable modules, and the one about to be tested by him appeared a good type for that purpose. The apparatus illustrated in Fig. 15 (page 522) could also be used for the discharges mentioned, but the success of both types depended on the absence from the water of long straggling grasses and similar floating matter. It was interesting to learn that the Dethridge meter had been found so successful in Australia. Of the various irrigation meters, this one appeared to be the least susceptible to interference by unauthorized persons.

The chief difficulties referred to by Mr. Clemence, which had been experienced in connexion with apparatus described in the Paper, arose from friction of working parts, but this had not been found by the Author to be so serious as Mr. Clemence stated. In most forms of so-called "equilibrium" valves, trouble also arose from the fact that whilst they might be in static equilibrium, it did not necessarily follow that they were in equilibrium when the water was in motion. The common "butterfly" valve, which consisted of a flat circular or elliptic plate fixed on a spindle passing through a diameter of the pipe, was a case in point. Such a valve was in equilibrium when it was closed, but when opened, the action of the water flowing past tended to close it again. The cure for such troubles was good design, and increasing the forces controlling the valve. The method for increasing the controlling force described by Mr. Paterson appeared to be very effective.

When accuracy was essential, leakage became of some importance, especially if it were variable. In Fig. 11 (page 520), the water escaping past the piston *b* reduced the accuracy of that apparatus. In Fig. 13 (page 522), on the other hand, the parts were so arranged that there was no leakage. In the apparatus described by Mr. Greaves (page 546) there was likewise no leakage, but it had the disadvantage that it required to be calibrated. In modules of this type the discharge usually decreased after the

apparatus had been in use for some time, owing to the growth of incrustation in the siphon pipe, with consequent increase of friction.

In reply to Mr. Leitch, the tests of the Struben Venturi meter described on page 533 were conducted by passing the total discharge from the meter over a "V" notch. With reference to the "standard" channels mentioned on page 535, a short length of the conduit, where the hydraulic slope was not likely to be interfered with by the operation of sluices, was constructed of a suitable form and calibrated, and a table or diagram was prepared showing the relation of depth of water to rate of flow. At any future time the discharge might be ascertained by measuring the depth of water and referring to the diagram for the corresponding discharge.

MEMOIRS.

John Blackburn was born in 1846. He received his engineering training at the works of Messrs. Tannett Walker and Co., Leeds, and subsequently remained in their employment as an engineer for nearly seven years. In 1870 he was engaged by the Canterbury Water Works Co. as engineer under the late Mr. S. C. Homersham, and five years later he became resident engineer to the Colne Valley Water Works, Bushey, Herts, where he was responsible for carrying out many enlargements and extensions of this Company's Works and system of water supply. This post he held until November 1915, when he retired on account of ill health. His death took place on 16th March 1916, at the age of seventy. He was elected a Member of this Institution in 1890.

Captain Alexander Charles Arbuthnot Bruce, A.S.C., was born in Edinburgh on 1st September 1889. He was educated at the Edinburgh Academy from 1897 to 1908, when he began an apprenticeship of five years with Messrs. James Milne and Sons, Ltd., of Abbeyhill, Edinburgh; and during a part of this time he studied at the Heriot-Watt Day College in the winter sessions, and also attended classes at Edinburgh University. He remained with the firm after the completion of his apprenticeship, but, on the outbreak of the War, having been a keen Territorial since leaving school, and being at the time a Lieutenant in the A.S.C. (T.), he was mobilized and stationed for a year in Scotland, during which time he obtained his Captaincy. The Lowland Mounted Brigade was then sent abroad, and as supply officer with it he served at Cape Helles for some months till the evacuation in January 1916. He was then ordered to Egypt, and was supply officer at Dueidar, near the Suez Canal, when an overwhelming number of Turks and Arabs attacked the oasis. Owing to a shortage of officers Captain Bruce

volunteered for any service, and held an outpost with a few men for some hours. Reinforcements arrived, but the relieving officer fell, upon which Captain Bruce went out to his rescue, but in doing so was mortally wounded, and died two hours later, on 23rd April 1916, in his twenty-seventh year. He was elected a Graduate of this Institution in 1914.

Howard Butters was born at Banbury, Oxon, on 30th August 1877. His early education was received at Stranraer School, Bournemouth, and the Camberwell Grammar School. Having an inclination towards engineering, he studied during 1892–93 at the Goldsmiths' College, New Cross, and at the age of sixteen he was apprenticed for four years to Messrs. Woodhouse and Mitchell, engineers, of Brighouse, Yorkshire. At the end of the term in 1897 he stayed with the firm as draughtsman until 1899, when he became chief engine draughtsman at the Low Moor Iron Works. While in this position he brought out a new valve for large engines, but owing to breakdowns of health he was unable to pursue the matter further, and, through consumption of the lungs, went to New Zealand, where he regained his health. He developed an engineering business, chiefly connected with fencing, sawmills, and the timber traffic, and invented a form of fencing for large areas, which was cheap, effectual, and had a large sale in New Zealand and Australia. In conjunction with Mr. G. R. Hale he founded in 1906 the firm of Butters, Hale and Co., of Napier, and he designed special machinery for manufacturing this fencing.

In 1909 he started the Northern Timber Co. of New Zealand, and by constructing a railway across a swamp and introducing improvements in sawing machinery he made this large area of timber accessible on a commercial scale for European investment. Subsequently, as managing director of the May Morn Company, he was engaged in developing a much larger timber property, and introduced, by arrangement with Mr. Louis Brennan, a gyroscope mono-rail system for the whole railway which was to open up the estate. Owing to anxiety with regard to closing down the companies on the outbreak of the War, his health broke

down and he returned to England. Consumption had, however, taken too strong a hold on him, and his death took place at Chagford, near Exeter, on 24th April 1916, in his thirty-ninth year. He was elected a Member of this Institution in 1910; he had previously been a Graduate from 1899 till 1902, when his Graduateship lapsed under the Rules.

Lorenzo William Crosta was born at Nottingham on 6th October 1862. His scholastic education was received at St. Saviour's Schools, Nottingham, which was followed by a three years' technical course at the University College of Nottingham. On its completion in 1879 he began an apprenticeship in the works of Mr. J. B. Payne, engineer and millwright, of Chard, Somerset, which terminated in 1883, when he was engaged as draughtsman and subsequently assistant works manager to Messrs. R. R. Newlove and Co., engineers, Nottingham. From 1889 to 1895 he was foundry manager in the works of Messrs. John Taylor and Sons, Nottingham, and from 1895 to 1900 he acted as general manager of the same works. In 1900 he was appointed managing director of the Railway and General Engineering Co., Ltd., and the Midland Engineering Works, Nottingham, and a director of the Ames Crosta Sanitary Engineering Co., Ltd. These positions he held until shortly before his death, which took place, after a long illness, at his residence at West Bridgford, Nottingham, on 22nd June 1916, in his fifty-fourth year. Among the various inventions and improvements he brought out may be mentioned a surface water gully, pipe-joints, tramway check on guard rail, rail grinder, tramway point adjustment, etc. He was a Graduate of this Institution from 1885 to 1889, and was elected a Member in 1900.

Captain James Samuel Davidson, Royal Irish Rifles, son of Mr. S. C. Davidson, of the Sirocco Engineering Works, Belfast, was born in Belfast on 9th March 1877. He was educated at the Royal Academical Institution, and the Campbell College, Belfast, and afterwards spent a year in Paris to acquire the French language. On 1st January 1895 he commenced his apprenticeship in the Sirocco

Engineering Works, and passed through the various departments. Five years later he became works manager, and remained in this capacity until May 1902, during which time he had under his charge the construction of machines for all the various processes in tea manufacture, and also the manufacture of centrifugal fans, propeller fans, drying machines, and other general engineering work. In June of the same year he became general manager and a director of the firm, which, at the outbreak of the War, was employing about 750 men. While taking a deep interest in the many ramifications of the business, he was more particularly identified with the tea-machinery branch, and personally brought out several improvements, including the Sirocco enclosed type of tilting tray drier, etc. Soon after the declaration of war the Ulster Division was formed, and Captain Davidson, who had been an active and energetic member of the 1st Batt. North Down Regiment Ulster Volunteer Force, was amongst the first to offer his services, and was given a commission as Second-Lieutenant in the 1st County Down Battalion, Royal Irish Rifles. He became Lieutenant, and shortly afterwards was promoted Captain. His knowledge of practical engineering was not long in being discovered, and he was appointed to the machine-gun section, subsequently being advanced to the position of Brigade-Captain of the 108th Infantry Brigade, Ulster Division, in which capacity he was commanding the machine guns at the time of his death, which took place, at the age of thirty-nine, in the great attack on 1st July 1916. He was elected a Graduate of this Institution in 1901, an Associate Member in 1903, and was transferred to Membership in 1907.

Sir Hay Frederick Donaldson, K.C.B., the second son of Sir Stuart A. Donaldson, the first Premier of New South Wales, was born at Sydney on 7th June 1856. He was educated at Eton and Trinity College, Cambridge, afterwards receiving technical training at the University of Edinburgh. From 1875 to 1877 he served an apprenticeship at the London and North Western Railway Works, Crewe, under the late Mr. F. W. Webb, and afterwards received further technical training, from 1877 to 1879, at Zürich

and at Cambridge. In 1880 he was employed on Parliamentary work and as engineer in charge of the construction of the Burnley tramways, and in September of the following year was appointed one of the assistant engineers, and shortly after an executive engineer, on the West of India Portuguese Railway and Harbour. During a part of his service here he was in charge of the harbour works at Goa. In 1887 he returned to England, and was soon appointed by the late Mr. Thomas A. Walker engineer in charge of No. 1 section of the Manchester Ship Canal, which work involved the construction of entrance locks, estuary banks and heavy piling work. After leaving the Manchester Ship Canal, he was engaged in 1891–2 in private engineering practice, and on 1st January 1893 was appointed Engineer-in-Chief of the London and India Docks Joint Committee, a position which he held until 31st December 1897, when he received the appointment of Deputy Director-General of Ordnance Factories, Woolwich, under the late Sir William Anderson.

Sir William Anderson died in 1898, and during the illness preceding his decease, and after his death, Mr. Donaldson, as he then was, was temporarily in charge of the Royal Ordnance Factories, and in 1899 was appointed Chief Mechanical Engineer. In 1903, on the retirement of Sir E. Bainbridge, he became Chief Superintendent of the Royal Ordnance Factories. The heavy responsible work, much of it carried on under very trying conditions, greatly taxed his health and strength, added to which were the great demands for guns and munitions for the present War. For his services he received the honour of Companion of the Order of the Bath in 1910, which was followed by that of K.C.B. in 1911. In September 1915, at the request of Mr. Lloyd George, he temporarily gave up his position at Woolwich in order to act as Technical Adviser at the Ministry of Munitions, and he frequently accompanied the Minister of Munitions on his visits to the chief industrial centres throughout the country; in the autumn he also visited Canada and the United States. It was as a representative of the Ministry of Munitions that Sir Frederick Donaldson, in company with Mr. Leslie S. Robertson (page 566), became a

member of the staff of Lord Kitchener on the visit to Russia, whose tragic deaths took place on 5th June 1916 by the sinking of H.M.S. "Hampshire" off the Orkney Islands. Sir Frederick was then nearly sixty years of age. For the purposes of this visit the War Office granted him the relative precedence of a Brigadier-General.

Sir Frederick took an active interest in the work of this Institution, of which he was elected a Member in 1898. He joined the Council in 1905, was a Vice-President in 1910, and occupied the Presidential Chair in 1913–14. During the first year of his Presidency the Institution held its Summer Meeting at Cambridge. This was the first time such a Meeting had been held at one of the older University towns, and, thanks to the admirable arrangements largely organized by the President and his late brother, the Rev. S. A. Donaldson, D.D., then Master of Magdalene and Vice-Chancellor of the University, the Meeting was a great success. At the Summer Meeting in Paris in 1914, about a month before the War broke out, he was at the last moment prevented from attending, owing to urgent matters at Woolwich. He read a Paper before the Institution in 1903, on "Cutting Angles of Tools," and gave an instructive Lecture to the Graduates in 1909, on "The Interchangeability of Screw-Threads." He took a most active part in developing the system of examination for Graduates and Associate Members, and made most earnest appeals to the members for establishing on a financial basis the Benevolent Fund of the Institution. He was a Member of Council of the Institution of Civil Engineers, and did excellent work in connexion with the Engineering Standards Committee, both as a member of the Main Committee and as Chairman of the Sectional Committee on Screw-Threads and Limit-Gauges.

Harry William Durham was born at Devizes on 17th May 1869. He was educated at Christ Hospital Day School, Ipswich, after which he attended evening technical classes at the Ipswich Science and Art Schools for five years. During this latter period, 1886 to 1890, he was receiving a practical training at the St. Peter's

Iron Works of Messrs. E. R. and F. Turner, Ipswich, and at the end of 1891 he became draughtsman and assistant to the works manager of Holtzapfel and Co., London. In February 1893 he joined the firm of A. Ransome and Co., Ltd., of Chelsea, wood-working machinery manufacturers, as draughtsman, and left in November 1897 to take over the management of Messrs. Holtzapfel and Co.'s works. Three years later he rejoined the firm of Messrs. A. Ransome and Co., as leading draughtsman, after their removal to Newark-on-Trent, and became head draughtsman in 1905, retaining this position until his death. During that period he brought out several inventions in connexion with wood-working machinery, in conjunction with the firm, and was a frequent contributor to technical journals. He completed a work entitled "Saws: their Care and Treatment" shortly before his death, which took place at Bournemouth on 18th June 1916, at the age of forty-seven. He was elected a Member of this Institution in 1914.

George Edwin Fuller was born at Chatham on 8th June 1860. After receiving a general education at a local school, he began in 1874 a seven years' apprenticeship in H.M. Dockyard, Chatham, and during that period he attended Science and Art Classes, obtaining various certificates for proficiency. In March 1881 he became a locomotive erector in the works of the London, Chatham and Dover Railway, and was appointed chargeman erector in February 1887. In December 1889 he went to South Africa, and worked in the shops of the Cape Government Railway for nearly three years, when he returned to England and rejoined the London, Chatham and Dover Railway. Two years later he was appointed running-shed foreman at the Battersea Works, and in 1900 he was transferred to Chatham, where he acted as district locomotive foreman at the New Brompton Works. In June 1903 he received the appointment of locomotive superintendent of the Gold Coast Railway, and after three years in this position he was appointed locomotive and traffic superintendent of the Benguella Railway, Lobita Bay. In August 1910 he became locomotive superintendent of the Chilian Longitudinal Railway, and two years later was

appointed chief locomotive superintendent of the Bolivar Railway, Venezuela. He returned to England in 1914 and was making a holiday tour in Germany when war broke out. The treatment he received during his internment undermined his health, and on his release he went on a voyage, but his death took place at sea from heart failure on 3rd May 1916, in his fifty-sixth year. He was elected an Associate Member of this Institution in 1909.

John Greenfield was born in London on 5th April 1856. After being educated at various schools, he began in 1874 an apprenticeship of five years at the Metropolitan Railway Works, Neasden, after which he was appointed assistant works manager in the Carriage Department of the same works. This position he held until 1892, when he became works manager of Pintsch's Patent Lighting Co., Ltd., London, and retained this post until August 1915. His death took place at Leeds, on 27th June 1916, at the age of sixty. He was elected an Associate Member of this Institution in 1912.

William Hanning was born in Paris on 21st February 1868. His scholastic education was obtained in Manchester from 1877 to 1882, and in Paris from 1882 to 1889. During this latter period he was trained by his uncle, Mr. James Hanning, mechanical engineer, and in 1889 he joined the staff of the American Otis Elevator Co., in Paris, being occupied in the building of the lifts for the Eiffel Tower. On the completion of the contract he started for himself in business as mechanical engineer in Paris, and acted as the representative of various English firms, namely, Hulse and Co., Thwaites Bros., Ltd., of which he became a director, Smith and Coventry, W. H. Allen, Son and Co., Grafton and Co., John H. Wilson and Co., etc. In this capacity he supplied large quantities of heavy machine-tools to the French shipbuilding yards, railway companies, etc. He was a Member of the British Chamber of Commerce in Paris, and successively became Member of Council, Vice-President, and President. During his Presidency this Institution held its Summer Meeting in Paris in July 1914, and

Mr. Hanning worked indefatigably in helping towards the success of the Meeting. On various occasions he had acted as British Juror at the Engineering Sections of Exhibitions, notably at Paris in 1900, Brussels in 1910, and Turin in 1911, and he was consulted by the British Embassy and British Consulate in Paris, on engineering matters. He was a great advocate of the Channel Tunnel scheme, and had hoped to take up the matter again this year. He also worked very hard to get the penny postage adopted between France and England. His death took place at his residence in Paris on 25th June 1916, at the age of forty-eight. He was elected an Associate Member of this Institution in 1901, and was transferred to Membership in 1911. He was also a Member of the Société des Ingénieurs Civils de France.

Albert Ernest Sculthorpe Minett was born at Fakenham, Norfolk, on 13th July 1883. He was educated at schools in Blackpool and Manchester, and in 1897 worked for seven months in the shops of Messrs. Heaton and Smith, electrical engineers, of Salford. This was followed by a year in the works of Messrs. S. Z. de Ferranti, Ltd., of Hollinwood. In September 1899 he went as an improver in the works of Messrs. Dorman and Smith, electrical engineers, of Salford, and two years later was engaged for a short time at the Birmingham branch of the Jones and Lamson's Machine Tool Co., of Springfield, United States. After a short term at the Deptford Station of the London Electric Lighting Co., he left in June 1902 to enter the Polytechnic School of Engineering, where he remained one year. He then studied at the City and Guilds of London Central Technical College until 1906, when he gained the diploma of A.C.G.I. In July of the same year he became assistant to the chief engineer of Messrs. Fry, Miers and Co., London, and was engaged on inspecting work, testing of boilers and engines, etc. In October of the following year he went to India to take up the post of assistant engineer in the Public Works Department in Burma, and subsequently became Executive Engineer of the Ruby Mines Sub-division of the Myitkyina Division. This position he held until his death, which took place at Rangoon,

after an operation for appendicitis, on 12th June 1916, in his thirty-third year. He was elected a Graduate of this Institution in 1903, and an Associate Member in 1912.

Leslie Stephen Robertson (formerly Robinson) was born at Kotagherry, India, on 4th October 1863, being the youngest son of Sir William R. Robinson, K.C.S.I., sometime Governor of the Presidency of Madras. He was educated in Germany and at King's College, London, and acquired his scientific training at University College, London, under Sir Alexander B. W. Kennedy (then Professor Kennedy) from 1883 to 1885. He was one of the organizers and the first Secretary of the University College Engineering Society. He next served two years at the works of Messrs. Denny and Co., of Dumbarton, and from 1887 to 1889 was in the drawing-office of the firm, being later appointed to superintend the Experimental Testing Department. After some experience at sea as engineer on board the R.M.S. "Jumna," he entered the drawing-office of Messrs. John I. Thornycroft and Co., at Chiswick. For a time he acted as works manager until he was put in charge of a large contract for the French Government at the works of the Société Anonyme des Forges et Chantiers de la Mediterranée, at Havre. On the completion of this work he visited the United States and Cuba. In 1892 he commenced private practice as a consulting engineer in Westminster, and six years later was joined by Mr. F. D. Outram, late R.E. Until 1898 he represented Messrs. Normand, of Havre, and had charge of their work in this country. He also acted as Secretary of the first section of the International Railway Congress held at the Imperial Institute, and accompanied the Commission on Light Railways appointed by the Cape Government.

Mr. Robertson contributed two Papers to this Institution, one in 1897 on "Mechanical Propulsion on Canals" and the other in 1898 on "Narrow-Gauge Railways." Amongst other literary work he translated and edited the English edition of M. Bertin's treatise on "Marine Boilers," and delivered a course of lectures on "Water Tube Boilers" at University College, London. In 1901 he was

appointed Secretary of the Engineering Standards Committee, and he was thus brought into contact with every British engineer of eminence. In July 1915, with the permission of that Committee, he was appointed assistant to the Director of Production at the Ministry of Munitions, and in this position he was concerned with organizing the production of the metal components of gun-ammunition. His knowledge of the engineering capacity of the workshops of Great Britain was invaluable in the important negotiations leading to the enormous increase in the output of munitions that has been accomplished. It was in this connexion that he became a member of Lord Kitchener's staff on the visit to Russia, and lost his life on 5th June 1916, in his fifty-third year, by the sinking of H.M.S. "Hampshire" off the Orkney Islands. For the purposes of this visit he was granted by the War Office the relative precedence of a Lieut.-Colonel.

Mr. Robertson was elected a Member of this Institution in 1892. He was also a Member of the Institution of Civil Engineers, the Institution of Naval Architects, and of other scientific societies. He was chairman and director of several companies, and a Freeman of the Pattenmakers' Company, of which he was Master in 1914.

Thomas Sipling Wilson was born at Hull on 4th November 1849, and was educated at the Old Grammar School in the same city. He began an apprenticeship in 1862 with Messrs. Thompson and Stather, of Hull, and on its completion seven years later he became head draughtsman to Mr. N. P. Burg, marine consulting engineer. In this position he was engaged on the preparation of plans for the protection of coast piers, etc., by the Hull Corporation Waterworks. In 1873 he joined the Native Guano Co. as engineer, and together with this post he carried on a consulting practice. After the termination of his agreement he acted as consulting engineer to the firm. In 1875 he became a partner in the firm of Messrs. Holroyd, Horsfield and Wilson, of Leeds, and in 1880, while still remaining a partner, was appointed engineer and manager to Messrs. J. Jenson and Co., fish manure and oil manufacturers, of

the Loffoden Islands, Norway. He acted as British Vice-Consul for the Loffoden Islands from 1882 until 1888. In the latter year he returned to Leeds, and again took an active interest in his firm. In 1905 he joined the firm of Messrs. Rose, Downs and Thompson, with which he remained until his death. His chief work was connected with the design and manufacture of machinery, presses, drying plants, etc., for fish, and with foundry practice, and he was responsible for many improvements in fish oils and fish manure plants. His death took place at Hull on 27th March 1916, at the age of sixty-six. He was elected a Member of this Institution in 1873.

Sir Corbet Woodall, D.Sc., was born in Liverpool on 27th August 1841, and was educated at the Crescent School in that city. His early knowledge of gas manufacture was obtained under his brother William, who was at that time manager of the Burslem Gasworks, but he served his apprenticeship to the late Mr. Robert Morton at the works of the Woolwich Equitable Gas Co., where he became Mr. Morton's assistant. In 1865 he obtained the position of gas engineer to the Corporation of Stockton-on-Tees, and while in their service he carried out the enlargement and reconstruction of the gasworks. While at Stockton he was consulting engineer to several companies in the district, and erected the works of the North Ormesby Gas Co. He left Stockton in 1869 and returned to London to enter the service of the Phœnix Gas Co., at their Vauxhall Works, of which Mr. Morton was then engineer. On Mr. Morton being appointed chief engineer of the London Gaslight Co. at Nine Elms, his former assistant was chosen as his successor at Vauxhall. This position he held until the amalgamation of the Company with the South Metropolitan Gas Co., when he gave up the active management of gasworks. In 1880 he commenced practice as a consulting engineer in Westminster; the practice rapidly increased, and there were few arbitration, Parliamentary, or other proceedings in connexion with gas undertakings of any importance in which he or his firm were not retained as advisers. From 1882 to 1900 he was in partnership

with the late Mr. Edward B. Ellington * as regards hydraulic power matters. He attained the highest position in the gas industry of the world when, early in 1906, he succeeded Sir William T. Makins, Bart., as Governor of the Gas Light and Coke Co. At that time the Company was making one-eighth of the gas supplied to Great Britain, and by the beginning of 1912, mainly through his instrumentality, the price of gas had been reduced by 5*d*. per 1000 cubic feet to 2*s*. 6*d*., at which it remained until war conditions compelled an increase. Two features in connexion with his tenure of this position stand out prominently, namely, the introduction of co-partnership and the formation of a corps of Territorials. The scheme of co-partnership has justified its adoption, and other companies with which he was connected have also adopted the system. He also introduced, in association with the London County Council, a scheme for the training of lads as gas-fitters, and another effort to produce competent workmen was the establishment of weekly lectures to the employees engaged in fitting and outdoor work. In 1913 he received the honour of knighthood by the King, and in the previous year the University of Leeds bestowed upon him the honorary degree of Doctor of Science. He was, from 1911, a Justice of the Peace for the Bromley Division of Kent. His death took place at Torquay on 17th May 1916, in his seventy-fifth year. He was elected a Member of this Institution in 1882, and was a Member of the Institution of Civil Engineers. He was a Member of the British Association of Gas Managers, of which he became President in 1878; and he was President of the Institution of Gas Engineers in 1913, the jubilee year of the organization.

Thomas William Worsdell was born in Liverpool on 14th January 1838. His father was at that time superintendent of the "Coaching" Department of the Liverpool and Manchester Railway, and remained with that Company, and its successive amalgamations into the final London and North Western Railway, for 52 years. After early schooling in Liverpool and Crewe, Thomas W. Worsdell

* Proceedings, I.Mech.E., 1914, page 1008.

went to Ackworth School for five years, and subsequently to Queenwood College in Hampshire. On leaving there he went into the railway carriage works at Crewe, principally in the timber yard department, but soon left to be apprenticed to an uncle in Birmingham, who was in business as an engineer and machine maker. Before completing his apprenticeship he was appointed a foreman in the shops at the age of twenty. The long hours and extra work caused his health to give way, and, after a serious illness, he was engaged at Crewe in the drawing-office of the Locomotive Department under the late Mr. John Ramsbottom. About two years afterwards he undertook the sole management of an engineering works in Birmingham for five years, but, the firm not keeping to their agreement, he left in 1865 for the Pennsylvania Railroad, where he was soon appointed Master Mechanic, having charge of their principal works at Altoona, Pa., and the construction of engines, cars, machinery, etc., and several iron bridges. He remained with that Company for $6\frac{1}{2}$ years. In 1871 he was appointed the manager of Crewe Works, and held that position for ten years, during which time very large extensions were made to the works. The Railway Company built all their locomotives and machinery, and had large steelworks which produced the castings, forgings, and, for a time, rails. Mr. Worsdell was a Justice of the Peace and a Member of the Crewe Local Board, being Chairman in 1875, when the disposal of the town sewage was re-arranged, and after the incorporation of the town was Chairman of Committees.

In the beginning of 1881 he was appointed Locomotive Superintendent and Mechanical Engineer of the Great Eastern Railway; during his time great extensions of works and lines took place, and here he designed and built 20 large compound passenger engines. In 1885 he accepted the post of Locomotive, Carriage, and Wagon Superintendent to the North Eastern Railway, and early in that year took charge of that department, remaining until the end of 1890, when failing health caused him to retire; but he was requested to continue as their consulting engineer for the mechanical departments. In the beginning of 1893

he retired, and, apart from some occasional consulting work, gave up further activities. His death took place at his residence at Arnside, Carnforth, on 28th June 1916, at the age of seventy-eight. He was a Member of this Institution during 1864 and 1865, and was re-elected in 1874; he served as a Member of Council from 1886 to 1892. He resigned his Membership in December 1915. He was also a Member of the Institution of Civil Engineers.

The Institution of Mechanical Engineers.

PROCEEDINGS.

October 1916.

The first Ordinary General Meeting of the Session was held at The Institution of Civil Engineers, London, on Friday, 20th October 1916, at Six o'clock p.m.; Dr. W. Cawthorne Unwin, F.R.S., *President*, in the Chair.

The Members present standing:

The President said it had been usual to make an announcement of the death of distinguished Members of the Institution. Since the last Meeting they had lost their Past-President, Sir H. Frederick Donaldson, K.C.B., who had been for a considerable time Chief Superintendent of the Royal Ordnance Factories at Woolwich; and Mr. Leslie S. Robertson, for a long time the Secretary of the Engineering Standards Committee, to whom the success of the work of that body was so largely due; also a very old Member, elected in 1859, Mr. R. Price-Williams, who had quite recently been made an Honorary Life Member in recognition of his long services to engineering. The Council had conveyed to the relatives an expression of sympathy on behalf of the Members of the Institution, and of their appreciation of the services which each had rendered to the engineering profession.

He thought the Members would desire that some tribute should be paid to those of their colleagues who had fallen in the service of their Country. So far as was known, twenty-nine Members (including Sir Frederick Donaldson and Mr. Robertson) had lost their lives on active service during the present War.

The Secretary read the list as follows:—

Bruce, A. C. A. (*G.*), Capt., A.S.C. (T.F.). Killed in action (Suez), 1916.

Casson, William (*M.*), Capt., 7th Lon. R. Killed in action (France), 1915.

Cunningham, F. L. (*G.*), Pte., Northd. Hussars. Died from wounds (France), 1915.

Davidson, J. S. (*M.*), Capt., Machine Gun Coy. Killed in action (France), 1916.

Deakin, G. W. (*M.*), Staff Capt., R.E. Died on Army service 1916.

Gilbert, David (*G.*), Corpl., R.N.D. Died from wounds and chill (Gallipoli), 1915.

Gordon, Vivian (*A.M.*), Capt., 8th Battn. Gord. Highlanders. Killed in action (France), 1915.

Haile, Edward (*G.*), Sergt., R.N.D., D.E. Died from wounds (Gallipoli), 1915.

Hollingsworth, Fredk. (*A.M.*), Lt., 1st Rhodesian Rifles. Killed in action (Rhodesia), 1915.

Howarth, John (*A.M.*), 2nd Lt., R.E. Died of wounds (France), 1916.

Inchley, William (*A.M.*), Lt., 2nd D. of Wellington's (W. Rid. R.). Killed in action (France), 1915.

James, W. Douglass (*G.*), 2nd Lt., R.G.A. Killed in action (France), 1915.

Johnston, A. D., Jun. (*A.M.*), Pte., Lond. Scottish. Killed in action (France), 1916.

Keyms, Thos. B. (*M.*), 2nd Lt., R.F.A. Killed in action (France), 1916.

Liley, H. D. (*G.*). Aeroplane accident (Shoreham), 1915.

McGroarty, R. D. (*G.*), Motor-Cyclist Scout. Died of wounds (Nairobi), 1914.

McNaughton, R. M. C. (*G.*). Accident on way to join Colours, 1914.

Northcott, H. H. M. (*A.M.*), Lt., R.N.V.R. Seaplane accident (Kent), 1916.

Okey, W. E. (*G.*), 2nd Lt., 1st Connaught Rangers. Killed in action (Mesopotamia), 1916.

Schneider, H. H. (*A.M.*), Lieut., R.E. Killed in action (Cameroons), 1914.

Taylor, C. G. (*M.*), Eng. Capt., M.V.O., R.N. Lost on H.M.S. "Tiger," 1915.

Tebbutt. O. N. (*G.*), Capt., 1st Battn. Camb. Regt. Killed at St. Eloi, 1915.

Vandell, H. I (*G.*), Lt., Northamptonshire Regt. Killed in action (Ypres), 1914.

Venning, T. A. (*A.M.*), Eng. Lt.-Commr., R.N. Lost on H.M.S. "Pathfinder," 1914.

Welsh, Anthony R. (*A.M.*), Lt., 4th Yorkshire Regt. Died of wounds (France), 1916.

Wilkins, F. T. (*G.*), 2nd Lt., 13th Northumberland Fusiliers. Killed in action (France), 1916.

Wilson, John (*A.M.*), 2nd Lt., Lowland Div., R.E. Killed in action (France), 1915.

The Minutes of the previous Meeting were read and confirmed.

The President announced that the following sixty-four Candidates had been duly elected:—

MEMBERS.

Archer, Jasper Snowdon, Major, M.M.G.C.,	Bisley, Surrey.
Bennett, Francis Frederick, . . .	Junin, Arg.
Common, Thomas Andrew, . . .	London.
Dymond, George Cecil, ...	Liverpool.
Hamilton, Alfred George, . . .	London.
Longley, John William, ...	Bradford.
Smith, Sydney, ...	Leicester.
Watt, Gordon Pollock, ...	London.
Wilson, John Hasel, ...	Sheffield.

ASSOCIATE MEMBERS.

Aked, William, ...	St. Anne's-on-Sea.
Allinson, George Leslie, . . .	Northampton.
Alliott, Eustace Alexander, . . .	Manchester.
Atkinson, Richard, ...	Liverpool.
Barrett, Edgar Bradley, . . .	Karteri, India.
Barton, Andrew Raynor, . . .	Harrow.
Bradley, Arthur Percy, 2nd Lieut., M.C.S.,	Dijon.
Brierley, Walter, ...	Kingston-on-Thames.
Broadfoot, John Whiffing Richmond, .	Midland Junc., W.A.
Buckton, Arthur Scott, Lieut., R.G.A., .	London.
Buswell, William Howard, . . .	Gisborne, N.Z.
Campbell, Alexander, ...	Aberdeen.
Cleary, Ralph Phillips, . . .	Perambore.
Cook, John William Donald, . . .	London.
Crossley, Alfred, ...	London.
Dale, John Hewitson, ...	Darlington.

Desprez, Charles Stanley, Lieut., A.S.C.,	Bristol.
Dicksee, Cedric Bernard, . . .	London.
Elliott, John Richard, ...	Woolwich.
Foster, John William, ...	Chilwell, Notts.
Fox, Carl, ...	Arequipa, Peru.
Gillies, Charles Malcolm, . . .	Sheffield.
Goulburn, Thomas, 2nd Lieut., R.F.C., .	London.
Gow, Walter, ...	Howrah, India.
Guilford, William Stephenson, . .	Boksburg, Transvaal.
Harrington, James, ...	London.
Hay, Peter Stewart, ...	London.
Heesem, Joseph Martin, ...	London.
Henriques, Wilfrid Quixano, Capt., M.G.C.,	London.
Hubbard, Charles Robert, . . .	Feilding, N.Z.
Jackson, Charles Laurence Hamilton, .	Ipswich.
Jenkins, Francis Thomas, . . .	London.
Keily, William John, ...	Leicester.
Kidd, Hector Charles Gordon, . .	London.
King, Henry George, ...	Leeds.
Kingsmill, Victor Henry, . . .	Belfast.
Leach, George Bertram, . . .	Rochdale.
Lee, Hoe Thye, ...	Kuala Lumpur.
McCallum, Percy, ...	Sheffield.
McCririck, John Douglas, . . .	Farnworth.
Maize, William James, ...	H.M.S. "Inflexible."
Murray, William Salmon, . . .	Aberdeen.
Pain, John, ...	Birmingham.
Pearson, Darrell Ulrick Ritson, . .	Calcutta.
Pelmore, Rudolf Albright, . . .	London.
Sinzininex, Edward Selby, . . .	London.

GRADUATES.

Burke, George Bernard, . . .	London.
Edmondson, Richard, ...	Manchester.
Flood, Charles John Maynard, . .	Chatham.
Martin, Alexander Elsden, 2nd Lt., A.S.C.,	Glasgow.
Menon, K. P. Padmanabh, . . .	Hyderabad.
Morgan, Humphrey Price Hughes, . .	Cheltenham.
Sims, George Arthur, 2nd Lieut., A.S.C., .	Brighton.
Wichmann, Axel Charles von, . .	Hove.
Wilson, Douglas, ...	London.

The President announced that the following twenty Transferences had been made by the Council :—

Associate Members to Members.

Aston, R. Godfrey, Major R.E.,	Longmoor Camp.
Brown, Robert Harry,	Birkenhead.
Clark, Frank William,	Dudley.
Cowlrick, Francis German,	Madrid.
Digby, W. Pollard, Capt. R.E. (T.),	London.
Edwards, William Sydney,	Stafford.
Gardner, Alfred Charles,	London.
Graham, James,	Kuala Lumpur.
Hilton, Nathan Lees,	Birmingham.
Horne, Professor Alexander Robert,	Aberdeen.
Jeffery, Charles Francis,	Assam.
Milne, Edgar Nesbit,	Buenos Aires.
Murray, John,	Durban.
Nash, Alfred William,	S. Russia.
Procter, Charles Gilbert,	Salisbury.
Saunders, Charles Henry Stanley,	Perambore.
Smith, Harold,	Manchester.
Sutherland, Donald,	Leith.
Temple, Frederick Charles,	Mozufferpore.
Watkins, William Gath,	Derby.

The President delivered a short Address.

The following Paper was then presented by Professor F. W. Burstall, *Member*, and discussed :—

> "Trials on a Diesel Engine, and application of Energy-Diagram to obtain Heat Balance"; by the late 2nd Lieut. F. Trevor Wilkins (Northumberland Fusiliers), M.Sc., of the University of Birmingham, *Graduate*.

The Meeting terminated at Half-past Seven o'clock. The attendance was 69 Members and 58 Visitors.

ADDRESS BY THE PRESIDENT,

W. CAWTHORNE UNWIN, LL.D., F.R.S.

It has not been usual for the President to make a formal Address at the opening of the Session in his second year of office. I do not know whether this is due to consideration for the President or is a measure of relief to members. In normal times I should not have departed from precedent. But with your acquiescence I should like to make a short statement, partly to explain the position of the Institution, partly to expand a point in my Address a year ago. I recognize that a statement by the President is not discussed, and that his views, if erroneous, do not commit the Institution. He is the more bound to be careful and moderate.

The conditions of the time have unavoidably restricted some of the activities of the Institution. We have placed our building at the disposal of the Government, and there is no immediate prospect of regaining the use of it. Happily, through the kindness of the Institution of Civil Engineers, who permit to us the use of their Meeting Hall and Library, the inconvenience to our members has been much diminished.

It is a difficulty that six members of the office staff of the Institution have been called up for Active Service, and it is inconvenient to the Secretary to carry on the considerable business of the office with untrained assistants. Nevertheless, so far the

Meetings have been held regularly; several provincial Meetings have been held, and the Journal has been issued as usual.

The Council decided that it was impracticable to hold the Summer Meeting, the Conversazione, or the Annual Dinner when so many members were absorbed in war work. In this they have taken the same course as other scientific societies.

The number of candidates for election does not seem to have been much affected by the war. Taking the first six months of the year, the number elected was 129 in 1914, 100 in 1915, and 112 this year. As would be expected, somewhat fewer candidates have presented themselves for examination.

Nearly 900 members of the Institution are known to be on Active Service, and many others are engaged on munition or other war work. Unhappily, so far as is known, 29 have died on service and 30 or probably more have been wounded. Our sincere sympathy goes out to their friends in their bereavement. They have died in a great cause and in the service of the country in its extreme need. So far as we know, 15 members on Active Service have been decorated and 8 mentioned in dispatches.

It would not be right to pass over, without an expression of our deep sorrow, the deaths of Sir H. Frederick Donaldson, K.C.B., a Past-President, and of Mr. Leslie S. Robertson, so long the Secretary of the Engineering Standards Committee. They were lost in the disaster to H.M.S. *Hampshire*, when accompanying Lord Kitchener on a mission to Russia.

There has been rather more difficulty than usual in obtaining Papers for the present session; but I trust we may have no mishap. We have tried to obtain a Paper dealing with the Work of Women in Munition Factories, but so far have not succeeded. It is believed that their services have been invaluable, and that for such work as they can undertake they are little inferior to male workers, either as regards quantity or quality. We hope to have one or more Papers on the special machinery for Shell Manufacture; also shortly a Report from the Hardness Tests Research Committee.

In my Address a year ago I urged that the rapid economic progress of Germany since the war of 1870, and chiefly in the last

twenty-five years, should be very carefully considered. Relatively, Germany has progressed in many industries much faster than we have. If we are to recover our position, as I believe we may do in the new conditions after the war, it is necessary we should study accurately the facts and causes of German expansion. No doubt that expansion has been too rapid to be healthy and seems to have induced a feverish sense of insecurity, so that under whatever inspiration the war began, it is certain that commercial and industrial necessities and ambitions had a large place. As an example which appeared to me remarkable, though it is only one of several, I referred to the iron and steel industry, in which not so long ago we were supreme, but in which we now hold third place and not a good one at that.

In a quarter of a century the production of pig-iron in Germany has trebled and that of steel has sextupled. In 1913 Germany produced 18 million tons of steel, and we produced 7 million tons. It is quite true that nations must depend on each other for products which each is best able to manufacture; but this hardly applies to the iron and steel industry. We have not been wanting in metallurgical knowledge nor obviously worse off in natural resources. Hence the rapid increase and present magnitude of the German production of iron and steel seems to me to have a lesson for us. German trade is conducted thoroughly and unscrupulously as a warfare, and it may well be that the fostering of the iron and steel industry is to be reckoned amongst the preparations that Germany made for war, for without a great capacity for iron and steel production the present war could not be prosecuted.

It is impossible to ignore the ambition frankly stated by Dr. Ostwald, the distinguished Leipzig professor, that Germany "having become the military centre of Europe, it was necessary for her to become the industrial centre also."

In a very interesting Address to the Royal Society of Arts, Dr. Dugald Clerk made a protest against the tendency to contrast unfavourably British achievements in science and industry compared with those of Germany. With most of this Address I heartily agree, and in any case I should differ from Dr. Dugald

Clerk with reluctance and even with some trepidation. Many years ago, Walter Bagehot wrote, "We English are always grumbling at ourselves. But, after all, England is a success in the world; her career has had many faults, but it has been a fine and winning career on the whole."

Dr. Dugald Clerk quoted my reference to the iron and steel industry and replied to it that "it is misleading to cite the relative production of iron and steel as proving either the prosperity of Germany or the decadence of England." As an explanation of the difference in this matter of England and Germany, Dr. Dugald Clerk says that "the United Kingdom has a total of 23,000 miles of railway and Germany has 38,000 miles," and that "it would be extraordinary if a capable and industrious nation, such as the Germans are, could not succeed in making most of the steel required for their own use." But he has forgotten that in India there are 33,000 miles of railway, almost as many as in Germany, mainly built and maintained by the use of English steel, and railways in other colonies naturally supplied from this country. The railway mileage test does not seem to explain the large German production of steel.

Dr. Dugald Clerk says also that the greater part of German steel is used at home. But how far is that true? In 1912 Germany exported a million tons of pig-iron and 4 million tons of steel partly manufactured.* In 1913 we imported from Germany iron and steel to the value of £7,500,000, and in addition machinery to the value of £2,300,000.† Take a single article, railway rails. Between 1908 and 1912, only four years, the export of rails from the United Kingdom decreased 10 per cent., that from Germany increased 16 per cent., and that from the United States 22 per cent. In 1912 both Germany and the United States exported more rails than we did. Now the iron and steel industry is a basic industry, the prosperity of it affects almost all other industries. We might get on without a dye industry, but the iron and steel industry is vital.

* Board of Trade. Iron and Steel, 1912.

† Sir L. G. Chiozza Money, M.P.

The impulse to the development of the German iron and steel trade came from the acquisition in 1871 of part of Lorraine containing 1,800 million tons of minette iron ore, followed by the discovery in 1877, by Thomas and Gilchrist, of the basic process. Probably Germany expected as one result of the war to annex the still larger iron deposits in the part of France now occupied by her armies. Mr. Ellis Barker has stated that the attack on Verdun was probably due to the wish to deprive France of her iron ore. It is probably true that steel is produced in Germany more cheaply than here. The works are on a very great scale and under the most able commercial and scientific management. German steel is almost exclusively made by the basic process. British steel is made chiefly by the acid process, which requires purer ore, and in fact a large part of our production is from imported ore. I believe we could produce more basic steel, and it is worth consideration whether a prejudice against basic steel justified in early days is now reasonable.

An influence which in the opinion of continental economists has been powerful in the development of German trade, is the system of Kartells which have been formed since the passing of rigidly protective legislation in 1879. One of them, the Steel Union, embraces thirty-one firms with an annual output of 12 million tons. Based on mutual consent, it controls the selling price of steel in each district, the area within which each selling agency may supply, the total annual output of each steel works, and the allocation among makers of the profits. It was ostensibly the object of this combination to reduce cost of production by regulating output and abolishing competition between firms in the syndicate. No doubt a less openly confessed object was to acquire selling monopolies and impose its own price on consumers.

It is alleged, that the Steel Union systematically resorts to dumping. In normal trade the price increased with the distance from the centre of production, being loaded with transport and other charges. In dumping the reverse is the case; out of profits made in a protected home market, bounties are given on exports to vanquish competition. For instance, from figures given by

M. Millioud, girders and rolled bars sold in Germany at 130 marks per ton were sold in England and South America at 103 to 110 marks, and in Italy, where it was desired to hamper a struggling industry, at 75 marks per ton. Sir Robert Hadfield has stated that before the war the export bounty granted by the Steel Union amounted to 15 marks per ton. The sale at a low price of an accidental surplus due to overproduction is one thing; deliberate overproduction in order to defeat competition abroad by dumping is another. Competent observers like M. Millioud believe that that has been the policy of the Steel Union.

Perhaps there is nothing illegal or which contravenes ordinary trade morality in a system of dumping. The Commissioner sent by the *Times* in 1901, to report on "American Competition," states that American manufacturers openly avowed the intention to keep up prices by stinting the home market in order to force the export trade by cutting prices in foreign countries. Possibly the importance of dumping may have been overrated. Continental economists do not seem to think so. But I do not believe that any nation subjected to systematic dumping will permanently submit to strangulation by an unfair trade method. It is not for me to suggest a remedy. No doubt one can be found and, personally, I hope it may not interfere with our custom of unrestricted trade.

To adopt a Kartell system with the protection which is its basis in Germany, would be contrary to our ideas and traditions. But dumping is not an essential part of association in trade. We may recognize that as Naumann says, in Mittel-Europa, "combination means the elimination of wasteful competition, economy of large production and gains from expert buying and selling on a large scale." It is a matter for consideration whether our trade methods have not been too individualistic. There would seem to be advantages in co-operation of firms, not merely to control labour, but in introducing methods of workshop organization, in pooling commercial and technical knowledge, in uniting in scientific investigations, and in establishing competent agencies in foreign countries. The Engineering Standards Committee is an example of advantages obtained by consultation and compromise without

interference with individual freedom, and standardization of production is likely to be much extended after the war.

Mr. Asquith said, "I lay particular emphasis on two tendencies. The first is the development of trade associations for common action at home and abroad, raising the average standard of production. The second is the recognition of the leeway we have to make up as regards scientific research and its application to technical and industrial purposes."

In August 1914 the Navy was ready, but in other respects we were unprepared for the war which was forced on us. But the way in which our characteristic unpreparedness, slackness and inertia have been overcome and organization created is extraordinary. It is an engineers' war, and mechanical engineers can realize the task involved in their department. Four thousand factories are under Government control, and the private workshops have been organized under local Committees and adapted to unaccustomed work of great precision. In Mr. Asquith's words, "the history of the war in the industrial sphere at home has been a history of grave and threatening difficulties, courageously faced and successfully overcome." In spite of the withdrawal of men for the front and the employment of a million and a half of men and nearly half a million women on munition and war work, ordinary activities have been kept going without serious embarrassment. But when the war is over there lies ahead another strenuous time. There will be the cessation of war expenditure, the return of the men at the front with physical and mental capacity enlarged by the experience and discipline of service, and the disposal of the women who, in munition factories and elsewhere, have been replacing men and earning unaccustomed wages. Still, there is no reason for pessimism. Our productive output has been enormously increased under war stress, and may be maintained in peace. There has been the creation of very large new engineering factories, older factories have been overhauled and equipped with new high-class tools. Manufacturers have co-operated in a way unknown before, and workshop methods and organizations have been improved. Industry has been modernized and invigorated.

Certainly relations between employers and employed have been unsatisfactory in the past. There are signs that the admirable co-operation which has been exhibited during the war has produced a better feeling. We may hope that with some increase in the rewards and improvements in the condition of workmen, deliberate restriction of output may be abolished. Adopted partly from false economic ideas, partly from natural anxiety as to wages and status as craftsmen, it has been, as Mr. Arthur Chamberlain says, effective, but at a terrible cost in loss of production.

TRIALS ON A DIESEL ENGINE, AND APPLICATION OF ENERGY-DIAGRAM TO OBTAIN HEAT BALANCE.

By the late 2nd Lieut. F. TREVOR WILKINS (*Northumberland Fusiliers*), M.Sc., of the University of Birmingham, *Graduate.*

Introduction.—The following Paper contains a description of some trials carried out on a small Diesel engine in the power-station at the University of Birmingham. The manner of conducting these trials and of working out the results enables the Author to present additional figures to those usually given in descriptions of similar investigations. The indicator diagrams obtained in the present trials were redrawn upon a heat-energy chart, and by this means any differences between the theoretical and practical cycles are clearly exhibited. Among the chief points of interest derived from this method of procedure were the following:—

(1) The amounts of heat passing to the cylinder-walls and to the exhaust were accurately determined. The heat-flow during the compression and expansion strokes was separately estimated; also in each case the period during which this heat-flow takes place was definitely indicated.

(2) Curves can be shown giving the temperature in the engine cylinder at any point during compression and expansion, and an accurate heat balance-sheet drawn up.

Summary of Method.—All charge quantities entering the engine cylinder were accurately measured; on the other side of the balance-sheet precautions were taken to obtain an accurate indicator-diagram. From these sources the volumes and pressures of cylinder charges of known weight and composition were estimated, enabling the indicator-diagram to be transferred to Professor Burstall's Energy-Diagram for Gases.* On this diagram the internal energy and temperature at any point in the cycle may be read off directly, thus making it possible to obtain a fairly approximate idea of the magnitude of the heat-flow through the cylinder-walls, and also of the periods in the cycle in which it takes place.

Description of the Apparatus used in the Trials.

Engine.—The engine was built by the Maschinenfabrik Augsburg and laid down in 1906. Since that date it has entirely been used for experimental purposes, probably running an average of only 100 hours per year. It is rated as developing 8 b.h.p. at 280 revolutions per minute, and is of the standard four-cycle, heavy cast-iron A frame vertical single cylinder construction. The cylinder dimensions as measured before the trials were 10·61 inches stroke and 6·50 inches bore.

Indicator.—The diaphragm optical indicator, Fig. 1 (page 589), expressly designed and constructed for these trials, is shown in section and plan in the general arrangement. The novel feature in the design is the means adopted for keeping the diaphragms at as uniform a temperature as possible. For this purpose Professor Burstall suggested the use of two diaphragms. These were connected at their centres by a stop, and through the space between the diaphragms steam was blown both when running engine tests and in calibrating the scale of the diaphragms, Fig. 2 (page 589).

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* Proceedings, I.Mech.E. 1911, page 171.

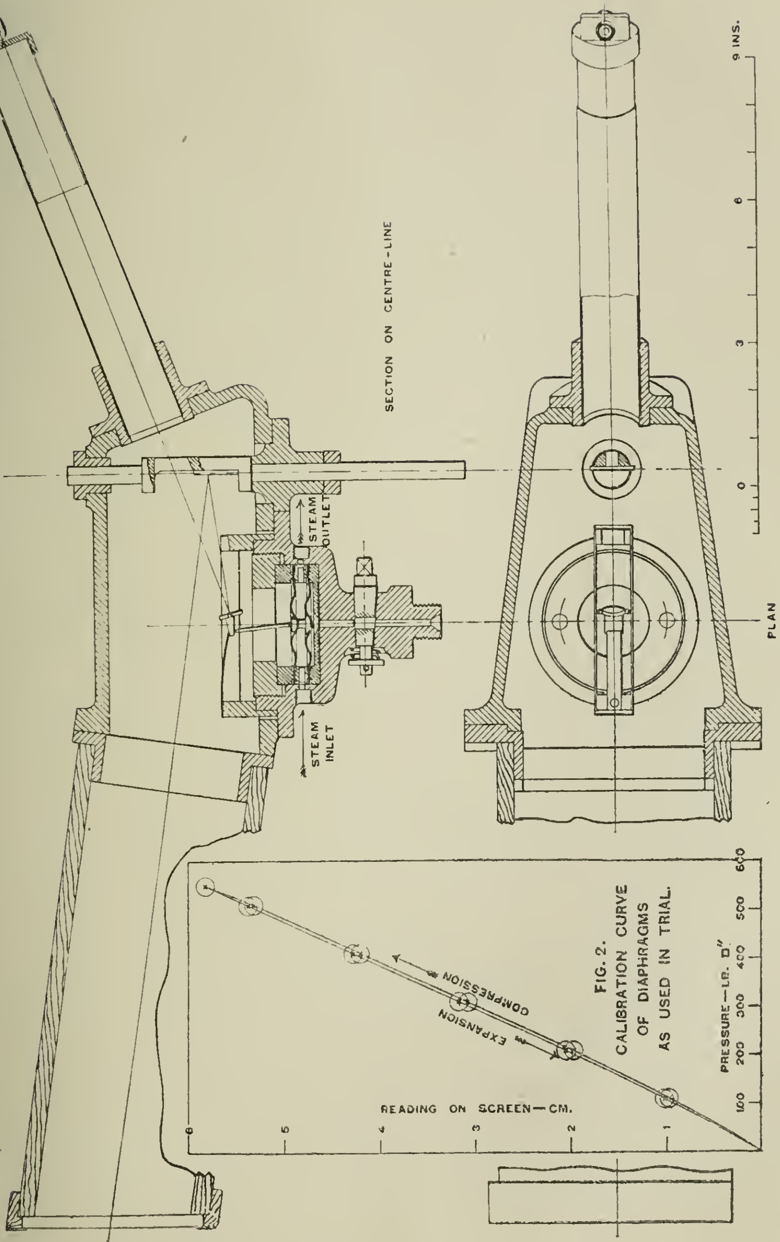


Fig. 1.—*General Arrangement of Diaphragm Optical Indicator.*

The indicator was calibrated immediately before and after each trial. A Crosby dead-weight gauge-tester was employed, care being taken to move the weights gently and to avoid all shock when altering the load. Two calibration diagrams were taken before and after each test, and the final scale adopted was the mean of those furnished by the four cards obtained. After scaling up the diagram and averaging the ordinates, the pressures were read off the calibration curve, and a mean indicator-diagram drawn to a large scale. This diagram was then carefully planimetered. When taking indicator cards, a rather long exposure was used, varying from 15 seconds in the half-load trial to 30 seconds at full load, Plate 3. The trace obtained on development gave, therefore, a mean card of from 35 to 70 working cycles. These long exposures rendered it possible for the number of cards taken during a test to be reduced to four only, but these were sufficient to represent from 140 to 280 cycles. For purposes of comparison the approximate area of each diagram was ascertained by finding mean heights, etc., and the greatest percentage differences obtained between the individual diagrams of a test were $1\frac{1}{2}$ per cent. in the case of the full-load diagrams, 2 per cent. at three-quarters load, and 3 per cent. at half-load.

Measurement of Injection Air.—In the engine as originally constructed, the first stage injection air-compression was carried out in the engine cylinder, an overflow valve in the cylinder head tapping off a small quantity of air at each compression stroke. The air then passed through an intercooler to a high-pressure compressor cylinder, in which the pressure is finally raised from 160 lb. per square inch to the pressure of the bottles. For the trials this overflow system was cut out, air being supplied to the compressor cylinder from a storage reservoir of known capacity, and pumped up to nearly the same pressure before each trial.

Measurement of Main Air Charge.—The air supply was measured by a Parkinson wet meter of 1,200 cubic feet per hour capacity, or 10 cubic feet per revolution. This meter was connected to the inlet pipe of the engine by an 8-foot length of 2-inch internal diameter

iron pipe; at the meter end of this was placed a cylindrical iron tank 4 feet 6 inches by 2 feet 6 inches in diameter. A throttling plate fitted between the tank and meter was adjusted until the pressure difference across the meter as shown by the water-gauge was practically steady. This arrangement quite effectively damped out the intermittent demand for air, the meter reading very steadily with a pressure difference across it of between $\frac{3}{8}$ and $\frac{7}{16}$ inch.

The meter was set in the standardizing position, and during the trials the water-level was maintained by means of a water drip. Light spring cards were taken off the engine before and after adding the meter, and no appreciable difference was noted. No air can pass through this type of meter without its measurement being recorded, unless the pressure difference is sufficiently great to depress the water-level $1\frac{1}{2}$ inch and to by-pass under the partitions of the air compartments. The occurrence of this is indicated by the noise produced.

Fuel.—The fuel used throughout these tests was supplied from one barrel of standard Royal Daylight paraffin. The oil was contained in a tank placed on the platform of a weighing machine, the scale of which was graduated to half ounces. To this tank a fine adjustment needle-valve was fitted, through which the oil dripped into a small brass vessel fitted with a gauge-glass. The quantity of fuel was measured by opening the valve sufficiently to keep the oil-level in the gauge-glass constant, and timing the drop of the weighing-machine lever at different increments of loading.

Cooling Water.—The jacket water was supplied from one or other of two calibrated gravity tanks. The temperatures at inlet and outlet were taken in thermometer pockets 6 inches from the inlet at the bottom of the water-jacket, and 3 inches from the outlet by the exhaust-valve.

Revolutions.—These were taken from a counter driven off the cam-shaft.

Load.—The load was applied by a rope brake, the ropes passing half round the fly-wheel and attached at the ends to two spring balances.

TABLE 1.

Test Results.

	Units.	Half Load.	Three-quarters Load.	Full Load.
Date of Trial		15.6.13	17.6.13	25.6.13
Duration	Min.	60	60	60
Barometer	mm.	753	748·5	755
Air Temperature	° C.	21·7	21·4	24·5
Revs. per Minute		277·17	275·07	271·97
Mean Ind. Pressure	Lb. per sq. in.	55·27	70·35	86·14
Cooling Water	Lb. per hr.	139	157	225·5
Inlet Temperature	° F.	75·4	75	81
Outlet Temperature	° F.	165·6	167·9	163·85
Blast-Pressure	Lb. per sq. in.	694	694	694
Injection Air	Lb. per hr.	6·86	6·5	5·13
Main Air Charge	Cu. ft. per hr.	1555	1538	1526
,, ,, ,,	Lb. per hr.	115·42	113·72	112·275
Fuel	Lb. per hr.	2·094	2·688	3·389
Mean Jacket Temp.	° F.	120·5	121·4	122·4

General.—All the instruments used in the trials were calibrated, and in working out the results the corrections are taken into account. The engine was started up from two to two and a half hours prior to the commencement of the test, and for an hour before the start was running under test conditions. The test

records were taken by one person only, and readings were taken in pre-arranged order at definite intervals.

Adjustment made during the Trials.—(1) The valve on the cooling water inlet-pipe was gradually opened in order to keep the temperatures at inlet and outlet constant. This was necessary, since the reduction in head as the surface of the water sank in the

TABLE 2.

Figures Deduced from Test Results.

	Units.	Half Load.	Three-quarters Load.	Full Load.
Indicated H.P.		6·81	8·61	10·42
Brake H.P.		3·89	5·73	7·57
Lost H.P. by difference		2·92	2·88	2·85
Mechanical Efficiency	Per cent.	57·1	66·55	72·7
Heat supplied	,,	100	100	100
,, as I.H.P.	,,	44·6	43·9	42·1
,, to Cooling Water	,,	32·2	29·2	29·6
,, Exhaust by difference	,,	23·2	26·9	28·3
,, as Brake Work	,,	25·5	29·2	30·6
,, ,, Friction	,,	19·1	14·7	11·5
Main Air Charge	Cu. ft. per cycle	0·1818	0·1805	0·1802
Oil per B.H.P. hr.	Lb.	—	—	0·448

gravity supply-tanks lessened the amount of water passing in a given time. This adjustment was not needed for the half-load trial and only slightly for the three-quarters load trial.

(2) The valve on the second stage injection air-compressor cylinder outlet was adjusted to keep the blast-pressure constant, as the compressor output varied with the lubrication.

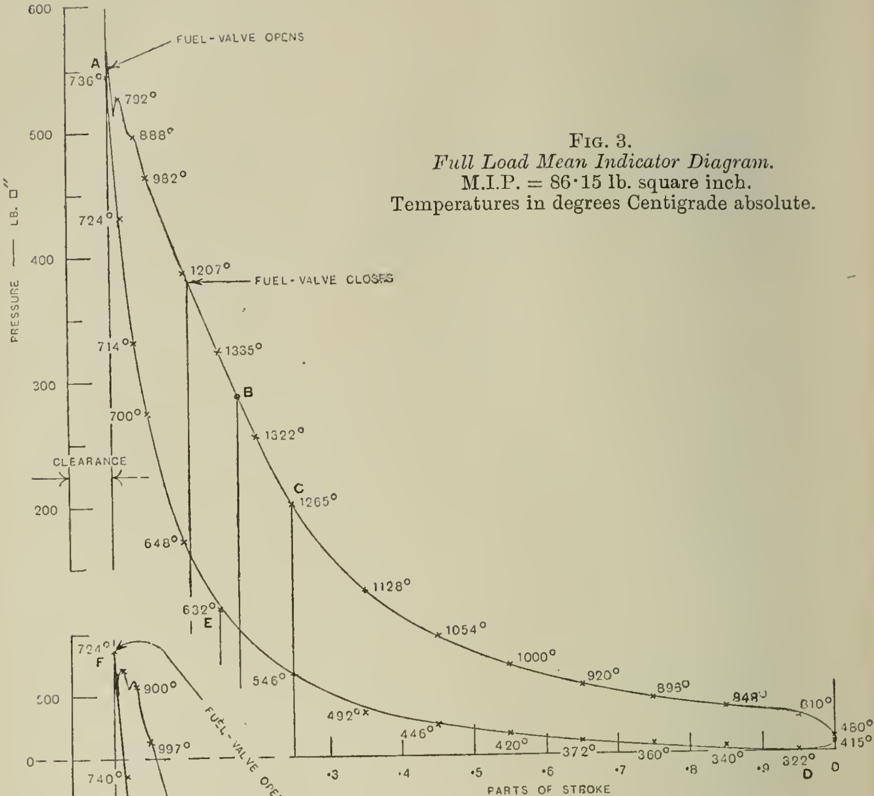


Fig. 3.
Full Load Mean Indicator Diagram.
M.I.P. = 86·15 lb. square inch.
Temperatures in degrees Centigrade absolute.

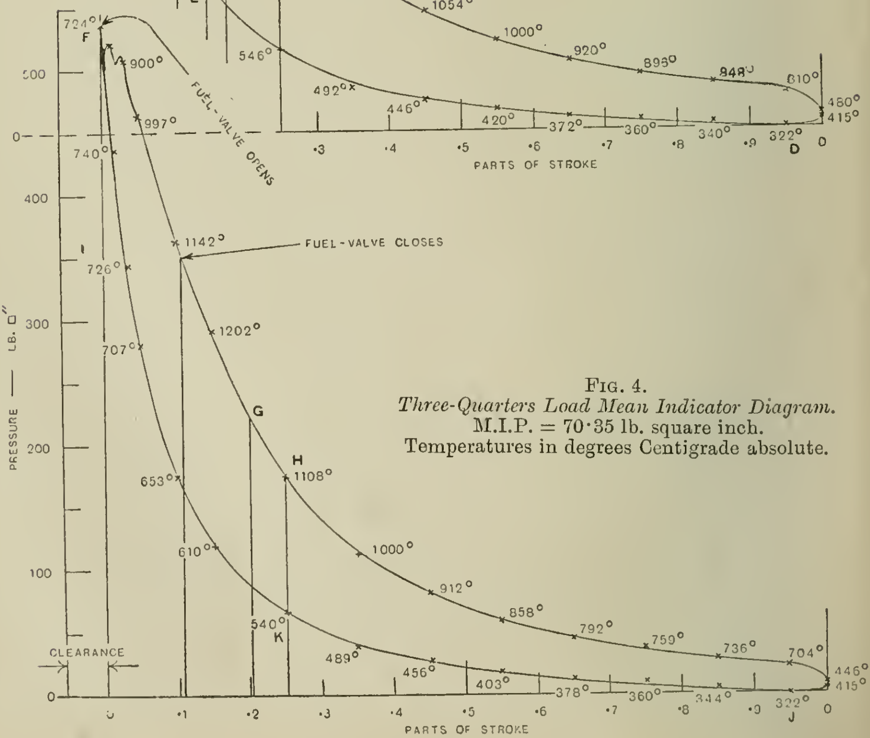


Fig. 4.
Three-Quarters Load Mean Indicator Diagram.
M.I.P. = 70·35 lb. square inch.
Temperatures in degrees Centigrade absolute.

(3) The spring balances were observed, and a constant difference maintained between their readings. No lubricant or cooling medium was used on the fly-wheel during the test.

The results of tests at full load, three-quarters load, and half load are given in Table 1. These figures are confirmed by many preliminary experiments.

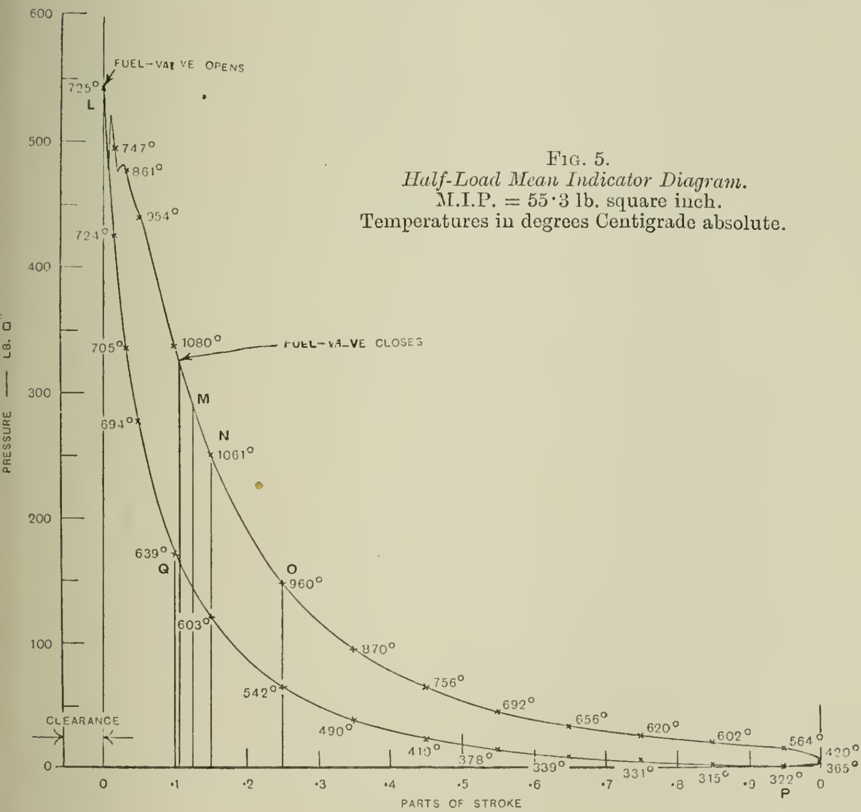


Fig. 5.
Half-Load Mean Indicator Diagram.
M.I.P. = 55·3 lb. square inch.
Temperatures in degrees Centigrade absolute.

Commentary on Apparatus and Test Results.—It will be noted that the quantity of air passing through the meter was somewhat in excess of the standardized capacity of that instrument, nevertheless the accuracy of measurement under the conditions given was stated

by the makers to be within 0·5 per cent. The figures given for the weight of injection air used are probably not reliable within 5·0 per cent. In these trials the mean jacket-temperature was purposely kept approximately the same, in order to keep the cylinder charge-weight as constant as possible. The diminution in charge-volume with increasing load is then due mainly to the higher temperatures of the cylinder-wall at the larger loads.

Indicator Diagrams.—A reference to the tops of the mean indicator-diagrams, Figs. 3–5, shows pronounced differences at each load. The manner in which the spraying of the fuel affects the efficiency is shown at half load, where it is apparent that the lower end of the spray-valve is not completely filled by the charge of fuel oil. It will be noticed that an appreciable time elapses before oil is blown into the cylinder and combustion begins. This is shown clearly on the energy-diagram. With increasing loads, since there is more oil in the fuel-valve, combustion begins earlier. Under these conditions, more oil is being injected than can be burnt immediately, and, as a result, after-burning takes place to a marked extent. At full load the combustion continues down the length of the stroke, whilst at three-quarters load the expansion more nearly approaches the adiabatic.

The Diesel Cycle on the Energy-Diagram.

General Remarks.—A short account of the construction and use of the energy-diagram is given in Professor Burstall's Paper.* This Paper includes an examination of the characteristics of the theoretical Diesel cycle when drawn on the energy-diagram. In the present Paper the Author considers the practical case only of the transference of actual indicator cards from an engine cylinder to the energy-diagram. To effect this transference the following information is necessary: the amount of the charge-weight and any two of the following four quantities, namely, pressure, volume, temperature, and internal energy. The charge-weight is measured

* The Energy-Diagram for Gas, Proceedings, I.Mech.E. 1911, page 171.

during the tests; pressure and volume are deduced from the indicator cards. The charge quantities measured in the trials are, however, composed of several elements, whilst the energy-diagram is drawn for 1 lb. of nitrogen. The charge quantity obtained on test must therefore be adjusted to obtain a weight of nitrogen, whose internal-energy changes will correspond to those of the substances in the engine cylinder.

The volume of this equivalent charge-weight multiplied by the reciprocal of its weight will give the volume occupied by 1 lb. of nitrogen at the given pressure. It is thus possible to take a series of representative points on the indicator card, to transfer them to the energy-diagram, and to determine readily the changes in internal energy and temperature during the compression and expansion strokes. To explain the method more in detail, a representative point will be taken on the expansion line of the full-load mean diagram.

Detailed Method of Transference.—The weight of nitrogen equivalent to the charge-weight of air is determined from the fact that for such gases as oxygen, nitrogen and air, the product of specific heat and molecular weight is constant—that is:

$$\frac{\text{Molecular weight of nitrogen}}{\text{Molecular weight of air}} = \frac{28}{28 \cdot 84} = \frac{\text{specific heat of air}}{\text{specific heat of nitrogen}} .$$

The weight of air drawn into the cylinder during the full-load trial $= 0 \cdot 01376$ lb.

∴ equivalent charge-weight calculated to nitrogen

$$= 0 \cdot 01376 \times \frac{28}{28 \cdot 84}$$
$$= 0 \cdot 013358 \text{ lb.}$$

On the working stroke when the fuel-valve is closed there is added a small quantity of injection air and fuel oil. The weight of these is as follows:—

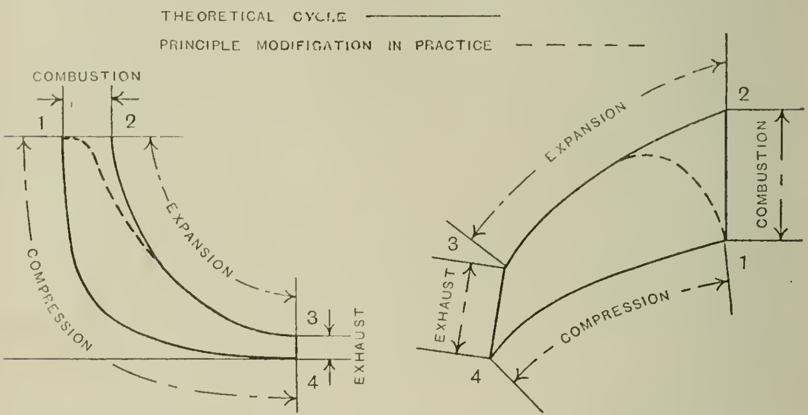
Oil	0·0004155 lb.
Air	0·000629 ,,

and are corrected to nitrogen in the same way as the air charge, thereby making of the full charge a nitrogen equivalent:

Fuel oil	Carbon	0·000824 lb.
	Hydrogen	0·000872 ,,
	Injection air . . .	0·000611 ,,
	Air change	0·013358 ,,
	Total equivalent charge-weight =	0·015665 ,,

Turning now to the mean indicator-diagram for the full-load tests, Fig. 3 (page 594), a point is taken where the piston is at 0.15

Fig. 6.—*Comparison of Diesel Cycle on Indicator and Energy-Diagrams.*



of its stroke, the pressure in the cylinder is 337·7 lb. per square inch, and the charge occupies 0·042485 cubic foot.

The volume occupied by 1 lb. of nitrogen under the given conditions

$$= 0{\cdot}042485 \times \frac{1}{0{\cdot}015665}$$

$$= 2{\cdot}718 \text{ cubic feet.}$$

On the diagram a perpendicular is erected from the point on the pressure scale corresponding to 337·7 lb. The intersection of this perpendicular with the constant volume line for 2·718 feet gives, when referred to other scales, the magnitudes of the internal energy and temperature of the cylinder charge.

To obtain the numerical value of the internal energy the value given on the diagram must be multiplied by the weight of the charge. For the point under consideration the values are :—

Temperature $= 1{,}335°$ C. Absolute.
Internal Energy $= 239 \cdot 5°$ C. Thermal Units per pound.

The internal energy of the actual contents of the cylinder will be

$$= 0 \cdot 015665 \times 239 \cdot 5$$
$$= 3 \cdot 752 \text{ Thermal Units,}$$

or

$$= 5{,}253 \text{ ft.-lb.}$$

By this method, points have been transferred throughout the expansion and compression strokes, and the result of joining up these points on the energy-diagram furnishes a redrawn indicator card, from which the following deductions may be made.

Deductions from the Study of the Energy-Diagram.

Deductions from redrawn Indicator Card.—To render the redrawn diagram quite clear, the two diagrams are shown side by side, Fig. 6, and each is numbered at the beginning and end of each operation in the cycle.

To investigate the manner in which heat transfer takes place on the expansion, it is instructive to divide up the stroke into periods, and to measure on the diagram the values of internal energy and temperature at the beginning and end of these arbitrarily fixed periods. The positions of such turning points are as follows: (1) at top dead-centre with the fuel-valve just opening; (2) the point at which rise in internal energy would seem to have ceased and (3) where expansion commences to follow the adiabatic law; and (4) that point in the cycle where all the output of energy ceases and a new cycle commences.

Taking the full-load expansion stroke, it will be seen in the first section AB on the diagram, Fig. 7, that $0 \cdot 60$ thermal unit is unaccounted for, or, rather, has either remained in the cylinder in the form of unconsumed fuel after the fuel-valve has closed, or else has passed out to the cooling water. It is probable that the greater

Fig. 7.—*Energy-Diagram.*

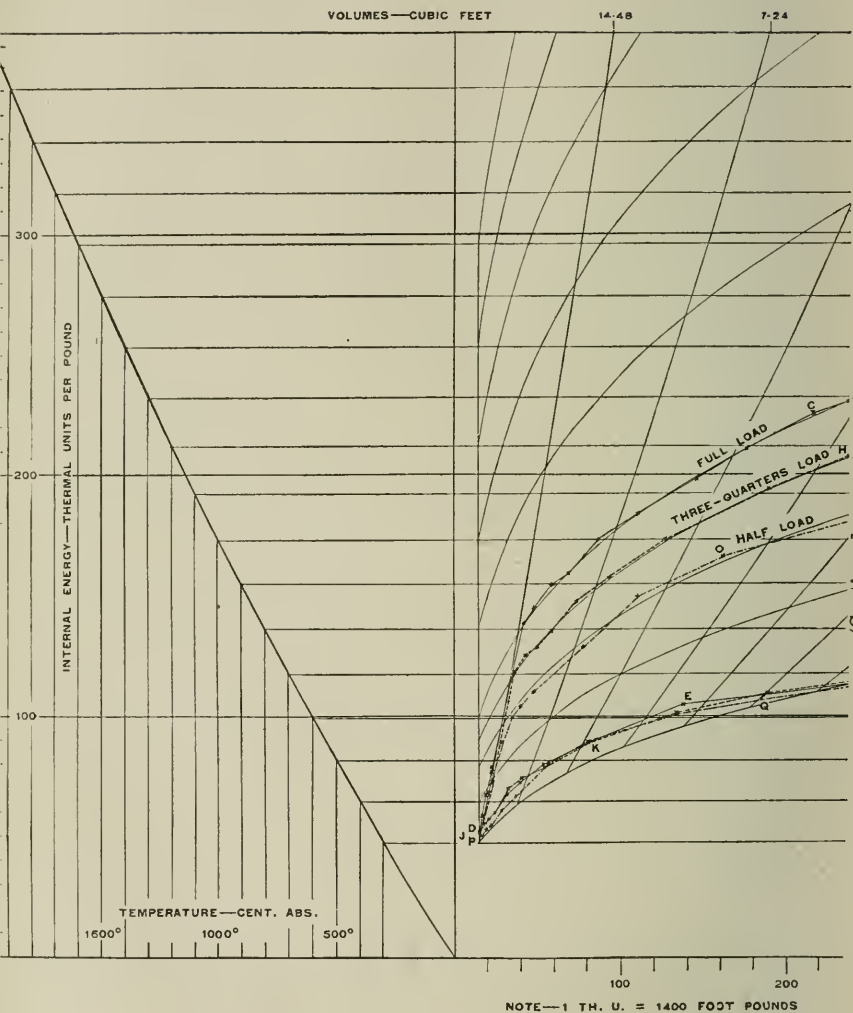


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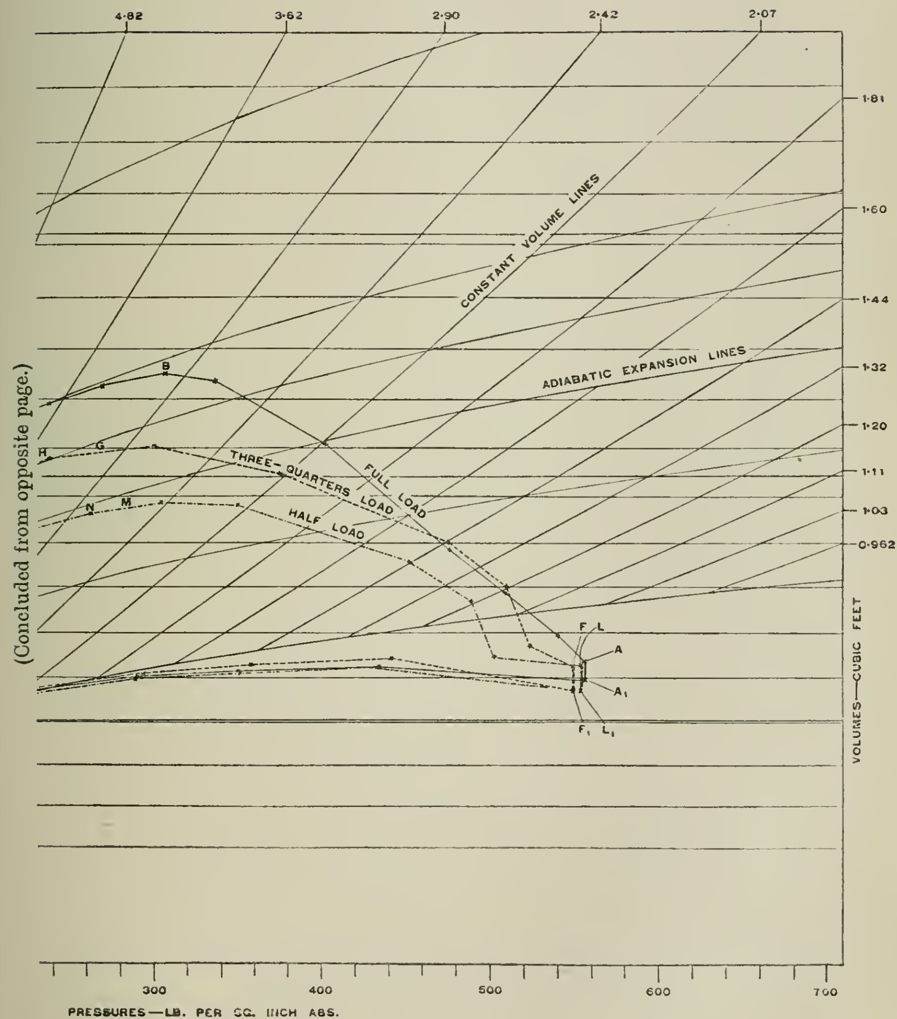
Fig. 7.—*Energy-Diagram.*



part of this heat has been imparted to the cylinder-wall, as in the next short section BC 0·107 additional thermal unit is required to make up the work to be performed by the piston. The work output during the successive periods of the stroke is determined by dividing up the original indicator-diagram by perpendiculars and planimetering the area lying between the expansion or compression lines and the line of zero pressure absolute. In the last section CD the expansion is practically adiabatic, the work to be done by the piston almost equalling the fall in internal energy whilst a negligible

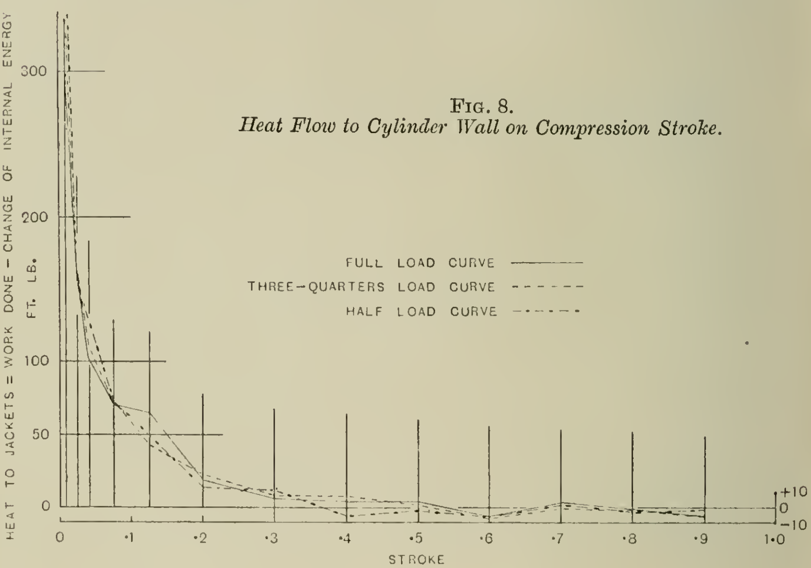


Fig. 8.
Heat Flow to Cylinder Wall on Compression Stroke.

amount of heat is supplied to the jackets. By arranging these figures suitably, it is possible to obtain the total heat-loss to the jackets during expansion and also the loss of heat to the exhaust.

The same process is followed for the three-quarters and half-load expansions, and the results are given in Table 3.

The compression strokes are treated in the same manner. In this case the turning point is taken at the place where the

TABLE 3.

Heat-Flow during Expansion.

—	Description.	Derivation.	Full-Load Trial.			Three Quarters Load Trial.			Half-Load Trial.			
		Period . . .	1 AB	2 BC	3 CD	1 FG	2 GH	3 HJ	1 LM	2 MN	3 NO	4 OP
1	Internal Energy of Charge at Start .	Energy Diagram	1·70	3·81	3·52	1·62	3·20	2·98	1·64	2·89	2·82	2·53
2	Internal Energy of Charge at Finish	Energy Diagram	3·81	3·52	2·08	3·20	2·98	1·75	2·89	2·82	2·53	1·44
3	Heat Supply	Fuel Measurement	4·3	—	—	3·36	—	—	2·62	—	—	—
4	Change in Internal Energy . .	(2) – (1)	2·11	0·29	1·44	1·58	0·22	1·24	1·25	0·07	0·29	1·09
5	Work done on Piston . . .	Indicator Card	1·59	0·39	1·40	1·62	0·23	1·20	1·21	0·16	0·43	0·99
6	Total Internal Energy Change .	(4) + (5)	3·70	—	—	3·20	—	—	2·46	—	—	—
7	Heat unaccounted for (Unburnt Fuel; Loss to Jackets) . . .	3 – (4) + (5)	0·60	—	0·04	0·16	—	0·04	0·16	—	—	0·10
8	Heat unaccounted for (Unburnt Fuel; From Jackets)	—	—	0·10	—	—	0·10	—	—	0·08	0·14	—
9	Total Loss to Jackets on Cycle .	7 – 8	—	—	0·54	—	—	0·19	—	—	—	0·04
10	Exhaust	Diagram.	—	—	1·38	—	—	1·04	—	—	—	0·94

TABLE 4.

Heat-Flow during Compression.

—	Description.	Derivation.	Full-Load Trial.		Three-Quarters Load Trial.		Half-Load Trial.	
		Period . . .	1 DE	2 EA	1 JK	2 KF	1 PQ	2 QL
1	Internal Energy at Start . . .	Energy Diagram	0·70	1·63	0·70	1·68	0·70	1·64
2	Internal Energy at Finish . . .	Energy Diagram	1·63	1·64	1·68	1·625	1·64	1·69
3	Change in Internal Energy . .	(2) – (1)	0·93	0·01	0·98	0·055	0·94	0·05
4	Work done by Piston	Indicator Diagram	0·87	0·66	0·90	0·67	0·83	0·72
5	Gain from Jackets	(3) – (4)	0·06	—	0·08	—	0·11	—
6	Loss to Jackets	(4) – (3)	—	0·65	—	0·72	—	0·67
7	Total Loss of Internal Energy . .	(6) – (5)	—	0·59	—	0·64	—	0·56

compression line makes a decided deviation from the adiabatic. Reference to the position of this point on the original indicator-diagram shows it to be within 15 per cent. of the end of the stroke. It will be noted that the heat lost to the cylinder-wall during compression takes place entirely at the top of the stroke. This is also the case during the expansion stroke, and indicates that the heat given to the cylinder-liner for the major portion of its length is derived by conduction from the top of the cylinder and in an engine of the trunk-piston type from the side thrust of the piston upon the cylinder-wall. This effect is shown very decidedly by the curves in Fig. 8, which show the rate at which heat is transferred from the charge to the jacket and vice versa. These curves are drawn from the information obtained by finding the changes of internal energy and work done over small fractions ($\frac{1}{60}$th) of the stroke and plotting these changes in the position in the stroke where they occur.

At present the opinion would appear to be that after-burning usually persists right down the expansion stroke. The figures obtained from these diagrams show that at full load there is distinct after-burning in the second quarter of the stroke, but that in the last part more heat is passing from the charge to the walls than is supplied by after-burning. At half load the heat which has gone to the cylinder-wall, when the piston is at the top of its stroke, is almost all repaid halfway down the expansion stroke.

Variation of Temperature in the Engine Cylinder.—Temperature curves, Figs. 9 and 10 (pages 606–7), have also been drawn both on stroke and on crank-angle or time bases. These curves and the original compression curve on the energy-diagram indicate clearly the small rise of the temperature of the charge with this diameter cylinder when the pressure on the compression stroke exceeds 300 lb. per square inch. Towards the end of compression the temperature appears to be constant for a short time and finally to fall slightly. This fall is shown clearly, and may be due either to the large surface and relatively small volume of the gases at top dead-centre, or to the cooling effect of a spray of cold injection air coming in when the fuel-valve is opening.

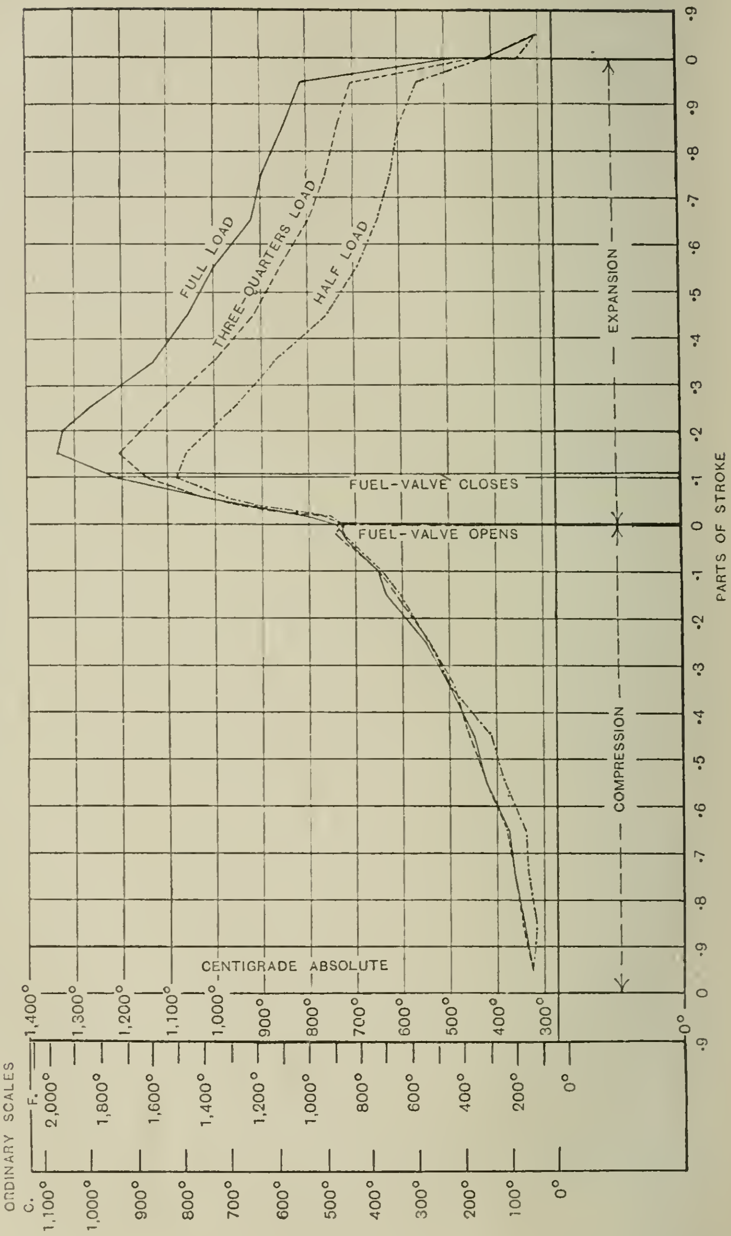


Fig. 9.—*Temperatures in Cylinder of 8 B.H.P. Diesel Engine on Stroke Basis. University of Birmingham, 1913.* (For particulars of Engine, *see* page 588.)

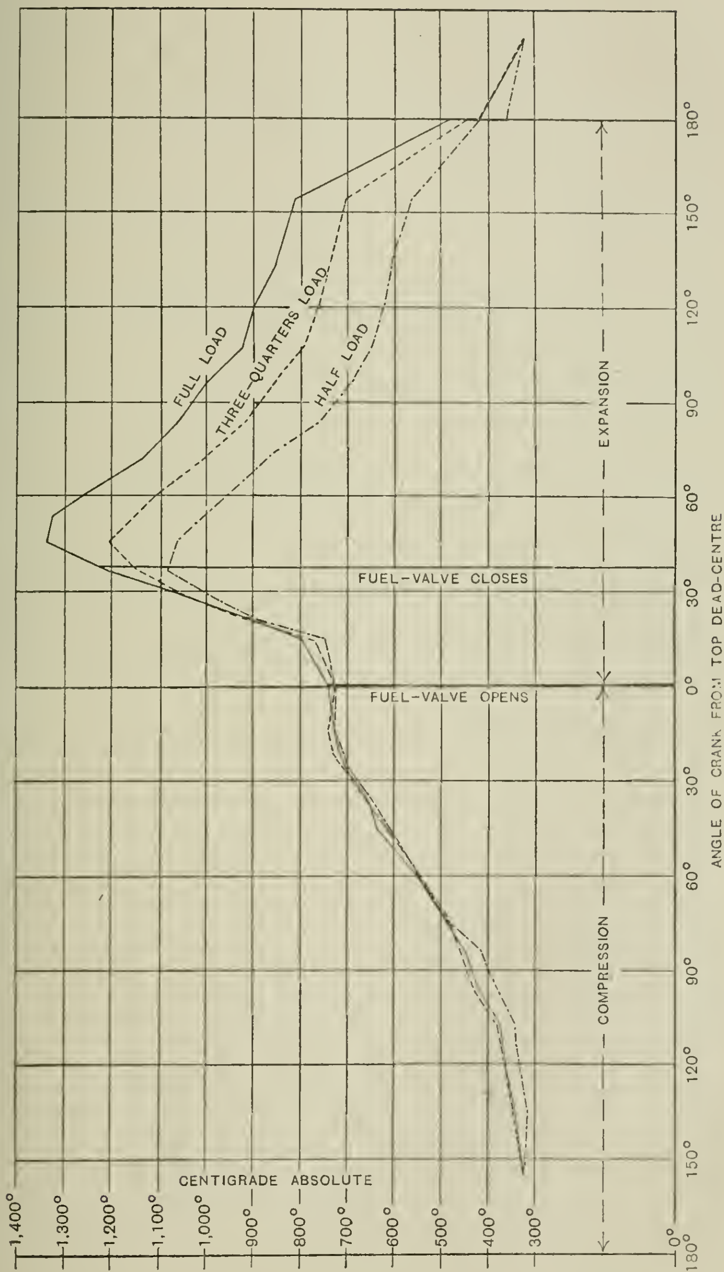


Fig. 10.—*Temperatures in Cylinder of 8 B.H.P. Diesel Engine on Crank-Angle Basis.*

TABLE 5.

Volumetric Efficiency and Charge Quantities.

Description.	Units.	Half Load.	Three-quarters Load.	Full Load.
Meter Reading corrected to 60° F. and 760 mm.	cu. ft. per hr.	1510	1490	1470
Volume of Charge per cycle	cu. ft.	0·1818	0·1805	0·1802
Weight of Air Charge per hr.	lb. per hr.	112·27	113·72	115·42
,, ,, ,, ,, cycle	,, ,, ,,	0·01383	0·01378	0·01376
Volumetric Efficiency on total vol. of cyl.	per cent.	84·2	83·7	83·6
,, ,, ,, inlet-valve closing	,, ,,	87·1	86·55	86·4
Temperature at end of suction (on piston sweep)	° C. Abs.	324	325	326
Injection Air per hour	lb. per hr.	6 86	6 5	5·13
,, ,, ,, cycle	lb.	0·000825	0·000788	0·000629
Oil	lb. per hr.	2·093	2·686	3·389
Oil, weight per cycle	lb.	0·00025124	0·0003255	0·0004155
Hydrogen, weight per cycle	,,	0·00003768	0·00004882	0·00006232
Carbon ,, ,, ,,	,,	0·0002135	0·0002766	0·0003531
Equivalent Charge-weights—				
Air Charge per cycle	,,	0·013476	0·013378	0·013358
Injection Air per cycle	,,	0·0008009	0·000765	0·0006106
Carbon per cycle	,,	0·000498	0·000645	0·000824
Hydrogen per cycle	,,	0·0005276	0·0006835	0·0008725
Total Charge-weight per cycle	,,	0·015303	0·015472	0·015665

Note to Table 5.

Total Vol. of Cylinder	0·2158 cu. ft.
,, ,, ,, ,, when Inlet Valve closes	0·2083 ,, ,,
Volume of Clearance	0·0119 ,, ,,
,, ,, Piston Sweep	0·2039 ,, ,,

Volumetric Efficiency.—The volumetric efficiencies are worked out upon volumes of air taken at 760 millimetres pressure. It will be noticed that they are high, and that the temperatures necessary to fill the cylinder are low. The correction for hot residuals will therefore be small enough to be negligible. A general check on the temperature figures is given by the comparisons of the thermal efficiencies obtained directly and by means of the energy-diagram.

Determination of True Percentage Balance-Sheet.—By combining the figures obtained from the indicator and energy-diagrams, the true percentage heat balance-sheet may be obtained and compared with the apparent balance-sheet obtained directly from the test results. The procedure followed in working out the figures is self-explanatory from the Tables.

TABLE 6.

Determination of True Percentage Heat Balance-Sheet.

—	Half Load.	Three-quarters Load.	Full Load.
	Quantities in foot-pounds.		
Work area under Expansion Curve .	3901	4264·6	4728·6
,, ,, ,, Compression Curve .	2151·05	2195·1	2170·7
(A) Useful Work per cycle . . .	1749·95	2069·5	2557·9
Heat to Jackets on Expansion . .	46·76	273·98	753·76
,, ,, ,, ,, Compression . .	832·02	907·3	768·04
(B) Total Heat to Jackets	878·8	1181·3	1521·8
(C) Total Heat to Exhaust . . .	1036	1460·2	1939·7
Total Heat per cycle (A + B + C) .	3664·7	4711	6019·4

From the figures in lines A B C the true percentage heat balance-sheet can be determined:—

—	Half Load.		Three-quarters Load.		Full Load.	
	Energy-Diagram.	Test Results.	Energy-Diagram.	Test Results.	Energy-Diagram.	Test Results.
Thermal Efficiency	47·7	44·5	44·0	43·8	42·5	42·1
Heat to Jackets .	24·0	32·2	25·1	29.2	25·3	29·6
„ „ Exhaust .	28·3	23·3	30·9	27·0	32·2	28·3
Totals . .	100·0	100·0	100·0	100·0	100·0	100·0

Attention is directed to the discrepancies between the figures obtained by each method for the value of the percentage indicated thermal efficiency. The differences provide an indication of the accuracy with which the measurements and graphical operations were carried out.

TABLE 7.

Amount of Heat Extracted from Exhaust Gases by Cylinder Cover.

—	Half Load.	Three-quarters Load.	Full Load.
Heat of Jackets . (Diagram) ft. lb.	878·8	1181·3	1521·8
„ „ „ . (Trials by diff.) ft. lb.	1173	1375	1781
Difference . . . . ft. lb.	157·2	193·7	259·2
Percentage amount . . ft. lb.	13·4	14·1	14·5

The differences at the same load in the percentage amount of heat going to the jackets in Table 6 are, of course, due to the fact that the cooling water extracts a large amount of heat from the exhaust gases on the exhaust stroke, as these gases, besides flowing

round the exhaust-valve, are directed to the outlet round a right-angled bend in the cover. The numerical values of these figures are determined, and attention is directed to the fact that the amount of heat extracted by the cooling water from the exhaust gases, expressed as a percentage of the total heat given to the cooling water, is remarkably constant.

Heat-Flow during Compression.—It will be seen in Table 8 that the figures for the heat-losses to the jackets are quite irregular, but, as may be supposed, the heat-loss at full load is appreciably less than at other loads.

TABLE 8.

Heat-Flow during Compression.

—		Half Load.	Three-quarters Load.	Full Load.
Loss to Jackets . . .	ft. lb.	832	907	768
Work done on Compression .	ft. lb.	2151	2195	2170·7
Percentage Lost Work . .	ft. lb.	38·7	41·3	35·4

The Author desires to express his thanks to Professor Burstall and Dr. Fisher of the University of Birmingham for the facilities afforded and suggestions given; to Professor Watson of the College of Science for the gift of two of his own diaphragms, which proved of great use in the preliminary investigations in connexion with the manufacture of the diaphragms for use in the indicator; and to his fellow research student Mr. A. U. Zimmerman and the staff of the University for their practical assistance.

The Paper is illustrated by Plate 3, and 10 Figs. in the letterpress.

Discussion.

Professor F. W. Burstall presented the Paper, giving an account of the experiments which were made under his direction, and of the problems and theory of the subject.

The President said the Members were extremely obliged to Professor Burstall for stepping into the breach and giving them such an excellent account of the work which had been done by the Author.

Captain H. Riall Sankey, R.E. ret. (Member of Council), said he thought the data of the Paper could be accepted with full confidence; he understood that they had been obtained by the Author under the supervision of Professor Burstall. The Paper, instructive as it was, had been made more interesting by the important information which had been given by Professor Burstall. He fully agreed with Professor Burstall that the future did not lie with the Diesel engine, but with the so-called—and miscalled—Semi-Diesel engine. In that connexion he would refer to almost the last words of Professor Burstall, where he called attention to the very high thermal efficiencies obtained in that small engine. Taking the three-quarters load it was 44 per cent., but on another page it would be found that the brake efficiency of the engine at that load was 66·5 per cent., so that the "brake" thermal efficiency was only 29 per cent. He thought it was probable that in the future, although the "Semi-Diesel" engine would not have so good an indicator thermal efficiency as the Diesel engine, it would have a better brake thermal efficiency, and that was what the user had to deal with.

In a great measure, the Paper was an application of Professor Burstall's energy-diagram which was published in the Proceedings in 1911 (page 175), but never discussed. It was a most interesting diagram. In that connexion he would point out that there were six

independent gas characteristics, of which any two could be plotted vertically and horizontally, usually to an equally divided scale, and the others could be shown by means of curves, or straight lines. The characteristics were: the pressure, the volume, the total heat, the internal energy, the temperature, and the entropy. The pressure-volume were a well-known pair of ordinates; as were also the temperature-entropy and the total heat-entropy (or Mollier chart). In Professor Burstall's Energy diagram,* Fig. 7 (pages 600–1), the ordinates were the internal energy and the pressure. It might be interesting to state that, out of those six characteristics, fifteen different kinds of diagrams could be made, of which, apparently, so far only the four above mentioned were actually in use. What there might be in the other eleven he did not know.

He thought, perhaps, it might be interesting to re-plot one of the indicator-diagrams in the Paper, Fig. 3 (page 594), on the temperature-entropy chart, so that it might be possible to compare that method of plotting with that adopted by the Author, Fig. 7, and that was done in Fig. 11 (page 614) for "Full load." The comparison could be made by means of the lettering, which was the same in both diagrams (*see* pages 600–1). Thus, beginning at point A on the extreme right of the Author's diagram, there was a small vertical rise which was represented approximately by the portion AM of the $\theta\phi$ diagram. Then the Author's diagram sloped to the point B, which was the highest temperature, and MB was the corresponding part of the $\theta\phi$ diagram. Then it dropped in temperature to the point C, then on to the point X (not marked on the Author's diagram), then to the point P and PD was a constant-volume line, which was shown on the Author's diagram as 14·48. The lower part of the Author's diagram was represented by the line DEA on the $\theta\phi$ diagram, and corresponded to the compression line on the indicator diagram.

All the various heat exchanges which were given in the Paper could, of course, also be followed on the $\theta\phi$ diagram. For example, it was pointed out in the Paper that substantially there was

* Proceedings, I.Mech. E., 1911, page 175.

(Captain H. Riall Sankey.)

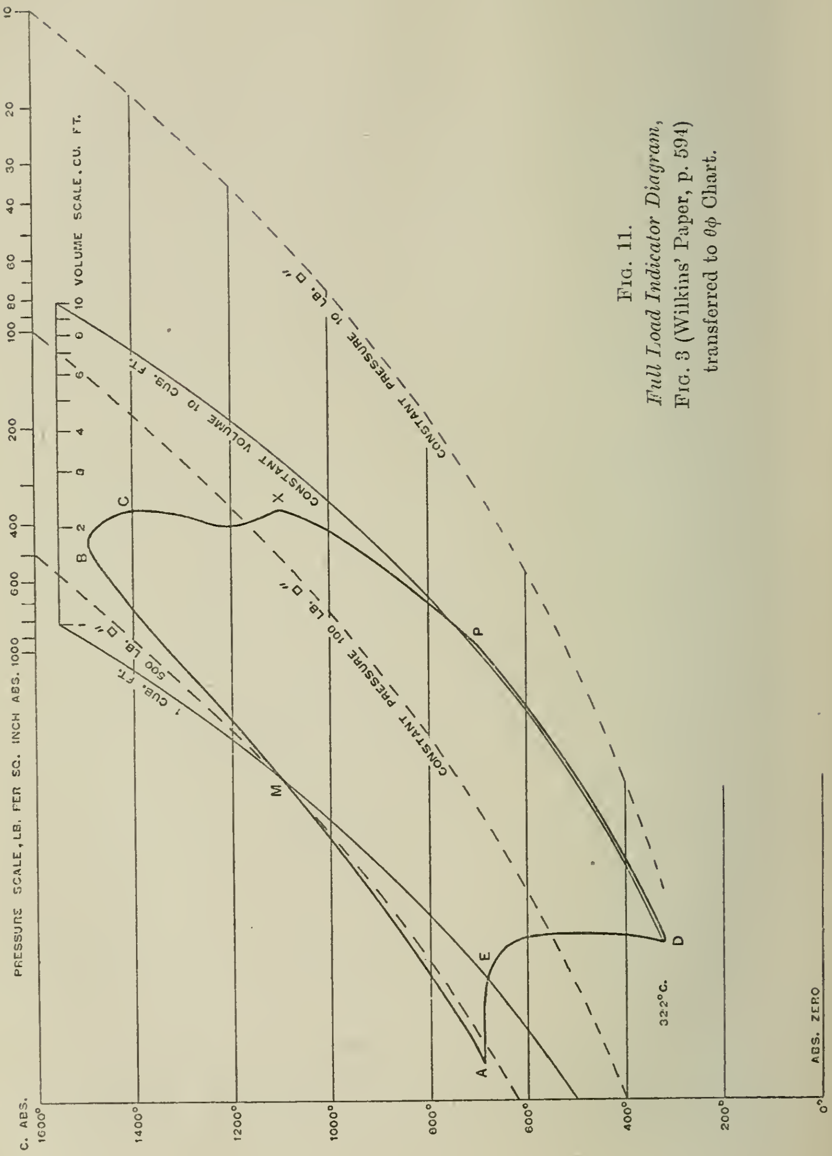


Fig. 11.
Full Load Indicator Diagram,
Fig. 3 (Wilkins' Paper, p. 594)
transferred to $\theta\phi$ Chart.

adiabatic expansion beginning at the point C, and CX on the $\theta\phi$ diagram was vertical. Also there was at first a loss of heat, regained later in the expansion, and this was shown on the $\theta\phi$ diagram. It was also stated that towards the end of compression the temperature was almost constant, which was shown by the portion EA of the $\theta\phi$ diagram being nearly horizontal. There was one difference, however: the maximum temperature shown on the $\theta\phi$ diagram was 1450°, as against 1335° C. abs. obtained by the Author. He (Captain Sankey) had not had much time to check the plotting, and this difference might be due to a mistake. But it might also be due to the fact that in the Author's diagram pure nitrogen was taken as the gas, whereas the $\theta\phi$ chart was drawn for the products of combustion in the Diesel engine.

He would like to ask Professor Burstall at what temperature the weight for the full-load trial on page 597 was taken; the figure was 0·01376 lb. Also he would ask why the initial temperature, that is, the suction temperature, was taken at 322° C. Abs. That meant that the temperature of the charge at the moment the piston started on its compression journey was 49° C. He thought that was rather a low temperature, and he would ask whether the temperature was actually measured by thermometer at any point of the stroke.

Professor Burstall had given a new definition of the words "full load." It was one of the difficult points in oil-engines, especially as it was commercially advantageous to put the full load much higher than it really ought to be in his opinion. What Professor Burstall had called three-quarters load, which he stated was the maximum commercial load, had a mean pressure of 70 lb. per square inch. So far as his experience went, even that was too high a pressure for a Diesel engine, and he would prefer to call the continuous rated load of a Diesel engine that at which it would work with 65 lb. mean pressure.

Professor E. G. Coker said that the Paper was extremely interesting, and bore evidence of very careful and scrupulous care to obtain accuracy in all the measurements for determining the

(Professor E. G. Coker.)

heat balance and the distribution of the flow of heat. Among the points which were brought out very fully was the detailed analysis of the temperature changes which were going on in the charge. Apparently in that engine, after-burning was going on throughout the stroke, and this phenomenon differentiated the case from that of the gas-engine.

In referring to the heat-temperature diagram, Fig. 9 (page 606) the Author gave the temperatures at the top of the peak for full load—he would retain the notation of the Paper—as about 1080° C. at half load, 1200° C. at three-quarters load, and 1330° C. at full load. That seemed rather higher than was found with a gas-engine of about the same power, but when it was remembered that these readings were from absolute zero, the agreement with gas-engine measurements was very satisfactory.

It might be of interest to give the determinations made with another internal-combustion engine, as they appeared to confirm the Author, although somewhat indirectly. In a "National" gas-engine which Mr. Scoble and he had tried at Finsbury,* they found that at about three-quarters load, with an average charge of air to gas of about 7 to 1, they got maximum temperatures under ordinary conditions varying from 1000° C. to 1050° C., and with a very strong charge, corresponding to about the maximum which the engine would stand, of about 1230° C. The latter figure was rather more than was obtained in a Diesel engine when the different zeroes of the two sets of measurements were taken. There were several points of interest in these diagrams, and the speaker would illustrate his remarks by aid of a diagram.

In the experiments which Mr. Scoble and he had made they obtained the temperature directly, except at the very top of the peak, and the temperature measurements for one trial were indicated on Fig. 12 by circles connected by strongly-marked curves, while some calculations of temperature, obtained indirectly, were shown in

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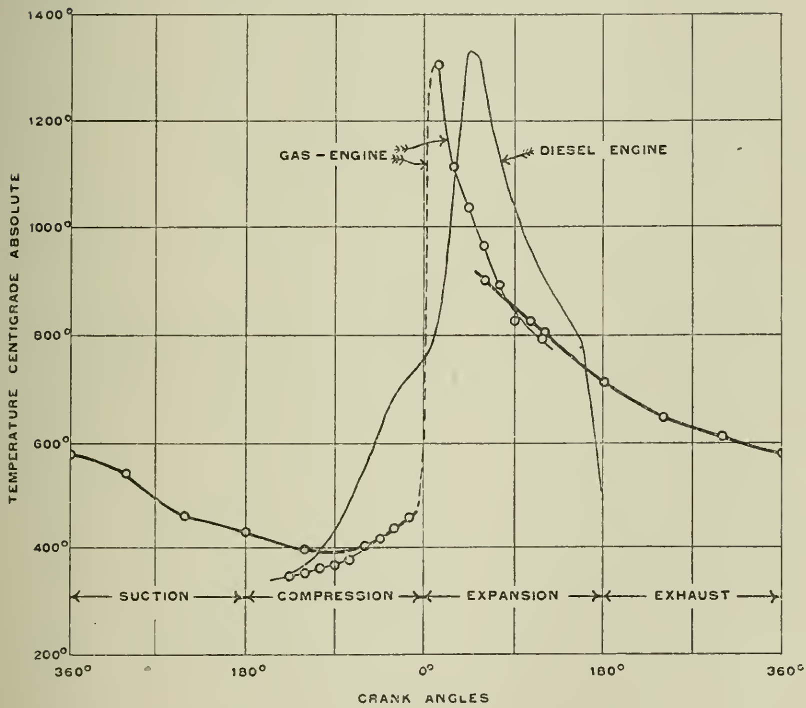
* "Cyclical Changes of Temperature in a Gas-Engine Cylinder," by Prof. E. G. Coker and Mr. W. A. Scoble. Proc. Inst. C.E., Vol. cxcvi, Part ii, 1913–14.

a similar manner, and connected by fine lines. At the end of the compression the temperature rose so rapidly that it could not be measured, and there was a gap, which included the peak, for which direct measurement proved to be unreliable, but for the remaining part of the cycle there were a good many points of observation.

Fig. 12.—*Cycle of Temperature Changes in a Diesel Engine and a Gas-Engine.*



The part not measured directly was filled in by observations from the indicator-diagram, and was extra-polated from the relation PV = RT where P and V were known and T was a value taken as high as possible on the expansion line of the diagram. The temperature diagrams in the present Paper showed some interesting variations, and for convenience of comparison the full-load temperature curve was plotted on Fig. 12, from which it would

(Professor E. G. Coker.)
be observed that at about the time when the fuel-valve opened there was strong evidence of a shoulder in the curve, followed by an upwardly sloping line, in marked contrast to the sudden change of temperature in the gas-engine indicated by the dotted line, and almost coincident with the zero ordinate.

He thought it was quite clear that the effect of the sloping line was due to the after-burning, and when the maximum temperature was reached the fall in temperature appeared to be similar to that in the gas-engine; but there was a shoulder shown which they did not find in their experiments at Finsbury, although, in looking the matter up that day, he had found in one or two cases there was a trace of a shoulder which they had apparently missed.

At the time when the Paper was discussed, it was suggested that probably these temperature measurements, which were obtained by intermittent readings, over a very small arc of the angle of revolution, could be obtained in a better way by using a thread galvanometer to get a continuous record of temperature. This form of experiment had been discussed previously, and, with the help of the Cambridge Scientific Instrument Company, further experiments were carried out and some temperature diagrams obtained which were shown at the Meeting of the British Association in Melbourne in 1914.* Plate 4 showed two of these curves, one being obtained when the gas-engine was running under the control of the governor, and the other when the governor was not operating, and firing was arranged to take place at every stroke.

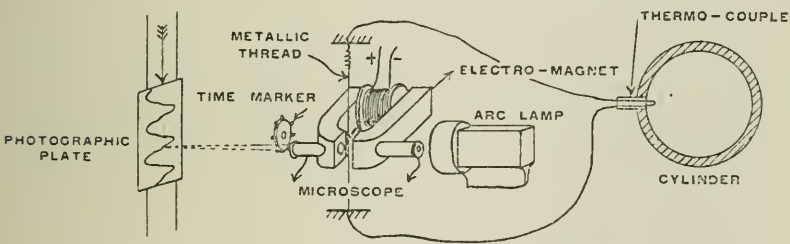
In these photographic records there were distinct pauses in the slopes of the rising and falling curves, the reasons for which were at present somewhat obscure, but they were mentioned here because the present Paper showed curves with similar characteristics. Mr. Eden was now investigating the action of the galvanometer under very rapid changes of E.M.F., like that produced in a thermo-couple when exposed to an explosion temperature, and also the lag of the couple itself. Some of the curves obtained

* "Temperature Cycles in Heat Engines," by Prof. E. G. Coker and W. A. Scoble, B.A., Report 1914, page 512.

appeared to show that the shoulder on the expansion curve occurred somewhat before the opening of the exhaust-valve, but only further experiment could decide if this was so, or if it was an effect due to the instrumental means employed. He found on the diagram in the Paper there was a shoulder, but Professor Burstall had informed him that this was due to the opening of the exhaust-valve. He would like to ask Professor Burstall whether he had found discontinuities, as described here, to occur in any Diesel engine which he had tried, or in any other engine of a similar character.

He might, perhaps, in conclusion, explain how the photographic records of temperature-changes were obtained. If a very fine wire, through which a current was passing, were stretched between the

Fig. 13.—*Apparatus for Photographing Temperature Changes.*



poles of the magnet in a direction at right angles to the field, it would be deflected perpendicularly to the lines of magnetic force, and if the ends were fixed, the motion at an intermediate point on the thread might be used to measure the current in the wire. The accompanying diagram, Fig. 13, showed the arrangement of the Einthoven galvanometer employed, in which an electro-magnet, with a very strong field between the poles, was provided with a microscope fitting into the pole pieces, to throw a magnified image of the moving thread on a photographic plate, which latter was allowed to fall at constant velocity. A time marker, operated by independent means, rotated in the field of view, and produced vertical parallel lines on the photographic plate at known intervals of time, in this case 0·04 of a second, while a cylindrical lens,

(Professor E. G. Coker.)

suitably divided on its face, marked equal intervals in a direction at right angles to the time markings. If the ends of the wire were connected to a thermo-couple exposed to varying temperature, the movement of the thread corresponded to the temperature of the couple, and this movement could be calculated to afford a measure of the temperature.

There must be some lag both in the couple and in the instrument, and in the diagrams which he showed, it could be seen that there was a little lag at the peak. But in both the upper part of the curve and the lower part of the curve there were distinct shoulders. He thought it was very probable that Professor Burstall had examined this point, and he would very much like to hear whether his measurements showed any trace of this. Very great care was taken in the design of the string galvanometer to ensure that the movement of the thread should be in phase with the change of temperature, or other phenomenon it was desired to measure, and the tension of the thread was adjusted to keep the deflection very small, and of the order of 0·01 of an inch, while the magnification was large—600 in the diagram used here—to give a reasonably sized diagram. Experiment showed that under these conditions the instrument was nearly dead beat in its indications, and with a scale of 1 milli-volt per centimetre the latest measurements of Mr. Eden indicated only a small amount of lag at the extreme points when a current was suddenly switched on to a circuit containing the galvanometer thread.

Mr. Michael Longridge (Vice President) said he would like to say one word on the question of full load. He was rather surprised to hear Captain Sankey suggest that 70 lb. mean pressure was a heavy mean pressure for a Diesel engine. In his experience he had found those engines could be worked perfectly well with heavy oils up to 90 or 95 lb., but when one got up towards the neighbourhood of 100 or 105 lb. then one began to get into difficulties. But as far as he knew, the mean maximum pressure depended a very great deal upon the injection pressure. With pressures such as Professor Burstall had used—about 650 lb.—one could not work at the above-

mentioned pressures with heavy oils, though apparently it was possible with paraffin; but with air-pressures going up towards 800 lb. there was not the slightest difficulty in working with mean pressures of 95 lb. and over. He thought the maximum practicable mean pressure depended very much upon the available air-pressure.

Captain Sankey asked to be allowed to thank Mr. Longridge for the correction and to confess to having made a mistake. The 65 lb. he had in mind at the moment was in connexion with the Semi-Diesel engine, and he wished to withdraw that remark in connexion with the Diesel engine.

Mr. E. J. Davis said that Professor Burstall, in speaking about the indicator, had stated, perhaps rightly, that the instrument which was being used was a perfect one, but, from the mechanical efficiency as given, it seemed rather low, and looking at the indicator cards, Plate 3, he found a possible reason for it. There was a swelling or a fattening on the expansion curve which he did not remember noticing before in Diesel cards. Of course, if the mean pressure as given was higher than the actual mean pressure, it would lower the mechanical efficiency.

As he had pointed out on Professor Hopkinson's Paper,* an optical indicator had one great disadvantage, namely, that the card was not fixed to the engine as it was in an ordinary indicator, so that, if the engine had any vibration at all, it was accentuated on the card itself, and it was liable to inaccuracy.

Professor F. W. Burstall said that Captain Sankey had put a question with regard to the temperature. The temperature of 60° was assumed; no temperature was measured at all. The difference between Captain Sankey's temperatures and those obtained from his own diagram were unquestionably due to the fact that Captain Sankey had used the products of combustion, whereas he himself had used pure nitrogen. His reason for using pure nitrogen was

* Proceedings, I.Mech. E., 1907, page 929.

(Professor F. W. Burstall.)

that while he had every confidence in Holborn and Henning's results with regard to pure nitrogen, he had not the same faith in their accuracy for water vapour, and he had therefore determined to use that which he was certain about, and leave the user of the diagram to correct for himself.

He thought Professor Coker's figures would be found to agree more nearly with those of the Author, if it were remembered that in the Paper the whole of the temperatures were absolute, whereas he thought the 1050° was a Centigrade temperature. If one added 273° on to that, the difference was not a very serious matter.

With regard to the point raised as to temperature, of course one could say a good deal, but he would only say this, that the whole thing was thoroughly worked out either at Leyden or Utrecht by a Dutchman named Petersen, who completely measured the temperature throughout the Diesel by the aid of an arrangement which he (Professor Burstall) had proposed to that Institution a good many years previously, namely, the combination of an Einthoven string galvanometer, a fine platinum wire, and a cinematograph camera. Of course, in the future one would never dream of attaching the movable plate to the engine itself. Naturally one would use a cinematograph and cause the film to travel at a fair rate past the spot of light, and that would remove all sources of error straight away.

Mr. Longridge stated that up to 90 lb. mean pressure he had had no trouble, provided the injection was taken up to 800 lb. He had had an injection pressure on the engine up to 1,400 lb., in the attempt to burn alcohol in a Diesel motor. But he confessed that they had a great deal more trouble with the high-pressure injections than with the low-pressure, and that was why they went back. They kept it as low as possible because, in agreement with Captain Sankey, he considered pressures of 800 or 900 lb. out of the question from a commercial point of view. That was why he disliked the true Diesel and preferred the Semi-Diesel engine. A compression of 200 lb. was the limit for practical commercial compressions in any form of internal-combustion machine. He had no doubt that very good results might be obtained at 105 lb.

mean pressure, but he personally had always been in difficulties when in the neighbourhood of 90 lb.

As to the question of an optical indicator not giving quite the correct results, he thought there was no doubt about that. It was a much more accurate instrument than any form of string indicator. It must be remembered that the engine was a very small one—only 8 h.p.—and he thought the results were very respectably good with regard to its mechanical efficiency.

He was sure that if anything could gratify the parents of the Author, who, he knew, felt his loss very acutely, it would be the fact that the Paper had been so well received by his countrymen. On behalf of the late Lieut. Wilkins, and not in the least on his own behalf, he thanked the Members for having listened to the last work of a very gallant young fellow.

The President said that the Paper would be a valuable contribution to the scientific knowledge of the internal-combustion engine. The Author had expended great care, patience, and labour on this research, and they all felt the deepest regret that he had fallen in the service of his Country; but they were fortunate in having the Paper presented by the Professor under whom he had studied.

Communications.

Mr. W. A. Benton wrote that among many exceedingly interesting points suggested by the Paper, he would like to call attention to the following:—

The Paper appeared to justify the view that the *exceedingly* high compression pressure in a Diesel engine was, apart from other

(Mr. W. A. Benton.)

considerations, a factor which made against a high thermal efficiency. The Author pointed out (page 605) that "Towards the end of compression the temperature appears to be constant for a short time and finally to fall slightly." No doubt both the explanations he suggested for this phenomenon were valid, namely, the large ratio of surface to volume of gases at top dead-centre, and alternatively "the cooling effect of a spray of cold injection air coming in when the fuel-valve is opening." The writer wished to lay stress on the former of these causes, for, obviously, if the compression of a gas were indefinitely increased while in contact with a cooling surface, there must be a point at which the ratio of surface to volume was infinitely great.

All this pointed to the possibility of eventually designing prime movers which should be more efficient as heat engines than Diesel engines. Further, it might be pointed out that the highest temperature of the charge was attained at a point in the cycle when the volume was changing very slowly. If an engine could be constructed in which the initial stages of expansion could take place at a rate approaching the piston speed at mid-stroke, a very large portion of the heat imparted to the cylinder wall during the last stages of compression, and at the moment of ignition, could be recovered. Unfortunately during the initial time-period of the expansion stroke, the rate of expansion was exceedingly slow, and consequently the ability of the gas to accept heat from the hot cylinder-wall changed very slowly. Even as it was, there was a return of heat from the cylinder-wall to the working fluid during the first portion of the expansion stroke, and the Author pointed out that "At half load the heat which has gone to the cylinder-wall, when the piston is at the top of its stroke, is almost all repaid halfway down the expansion stroke." This led the writer to call attention to the additional support which the Paper gave—more or less directly—to the now well-established doctrine that under actual working conditions in an internal-combustion engine, the intense heat imparted by the burning gases to the cylinder-walls was confined to a very thin lamina of metal, which was thus able to return heat to a rapidly expanding fluid in contact with it.

Apart from such a conception, it appeared to the writer very difficult to explain the high thermal efficiency of small high-speed petrol engines, and still more difficult to account for the high thermal efficiency of the Diesel engine. The loss of heat from the extremely dense gas to the relatively very large cooling surface, just before and after dead-centre, would affect the thermal efficiency much more adversely than it did if it were not for the "give-and-take" effect of the surface lamina.

In the early stages of gas-engine development in this country, Atkinson and others were alive to the importance of rapid expansion and slow compression in the cycle, and were definitely aiming at isothermal compression and adiabatic expansion. They also endeavoured to use a greater ratio of expansion than of compression. The modern theory of heat exchange between the surface lamina and the working fluid made it probable that, even if such engines as the Atkinson could be made mechanically satisfactory, their thermal efficiency would not be appreciably greater than that of the modern high-speed engine, unless, as suggested above, the initial portion of the stroke could be made at high velocity—a quite impossible condition in practice. If, during the initial portion of the stroke when heat was being rapidly communicated to the containing surface, the piston accelerated as slowly as it did in ordinary connecting-rod engines, no speeding up of the piston to a relatively greater velocity during the "expansion" portion of the stroke would effect any economy as against the simple high-speed engine, for its chief result would be to shorten the period during which the hot surface could return heat to the gas.

M. R. E. Mathot wrote that the perusal of this Paper would certainly be interesting to Diesel engine manufacturers, for it confirmed, notably, the valuable method of Professor Burstall's Energy-Diagram. It was only regrettable that such elaborate tests had been carried out on such an exceptionally small engine, for it minimized considerably the value of the data given, and much more because the engine was of a rather ancient construction and obviously did not embody the improvements found in constant-

(M. R. E. Mathot.)

pressure types of engines in common use. As a matter of fact, no industrial or marine Diesel engine of less than 35 to 50 h.p. per cylinder was used for actual service, with the exception of some special high-speed submarine motors. Valuable data on reliable heat balances should, therefore, preferably be deduced from tests on engines of a reasonable power as found in actual working conditions, and no general principles should be deduced from trials merely made on small laboratory machines of low efficiency.

Regarding the brake test, it should be observed that the rope passing half round the pulley was liable sensibly to affect the power output of a small engine, for the pull created an additional thrust upon the next main bearing, as the writer had observed by recording the difference of results obtained: (1) with the rope engaging with the upper half of the pulley; (2) with the lower half; and (3) with the rope around the whole circumference. The last-mentioned method allowed for a minimum negative weight to be deducted from the positive pull and assured more accuracy.

With respect to the engine itself, as used for the tests, it would be observed, from Table 1 (page 592), that the M.I.P. expressed in lb. per square inch was 55·27 for half load, while it was only 86·14 for full load. The designation applied to one of these two figures was apparently wrong; either the full-load figure should be about $55 \times 2 = 110$ lb., or the half load figure $86 \div 2 = 43$ lb. In good constructions of Diesel engines the M.I.P. was normally 100 lb. for "constant working full-load power," while it reached from 115 to 120 lb. for "momentary" overload, which involved a margin in power of about 15 to 20 per cent. Therefore the thermal efficiency should always be mentioned in relation to the load rated with about 100 lb. M.I.P., which corresponded, as a rule, to the best mechanical efficiency and the lowest consumption.

Table 2 (page 593) showed the poor quality of the engine tested, as the mechanical efficiency for full load was only 72·7, while 75 per cent. might normally be expected from even multi-cylinder engines of this type. The writer was, moreover, of the opinion that the mechanical efficiencies relating to half and three-quarters loads were without significance or technical value. The thermal

efficiency of 30·6 per cent. resulting from the high consumption of 0·448 lb. of oil b.h.p. hour recorded at full load, by the Author, was also very poor, when it was considered that these figures respectively reached 35 per cent. and 0·4 lb. in good modern Diesel engines. The expression "full load" was, in itself, rather vague if no figure for over-load was also not mentioned, so as to show what was really the power capacity, or the exact rate to which the full load related. Also, the fuel injection seemed to have taken place too late. It appeared that if it had been regulated for occurring earlier, better combustion could have been obtained, for it would have raised the straight shaped line that started with the expansion stroke along about one-third of its length, Figs. 3 and 4 (page 594). He understood, of course, that the engine at the University was taken as it stood, but it showed again that best conditions for high-class results were not met with in the little Diesel engine used for such scientific research. Engineers should therefore be warned against the danger of relying on the data given as representing definite laws applicable to actual Diesel engine practice. These observations of the writer's were not, however, intended to prejudice the value of the Paper, which remained a valuable document with respect to the proper way of conducting scientific trials of this nature.

With respect to actual figures obtainable from up-to-date Diesel engines, the members of this Institution might be interested in the Table (page 628) of abridged results of tests the writer conducted, in Hanover, shortly before the war broke out, on a German-made Diesel engine, which had since been in actual operation in a central power-house in California. Some of the indicator cards were also added, Fig. 14 (page 629); they were just taken among the lot, and were not selected for the purpose. The full, three-quarters, one-half and one-quarter loads were carried out during 24 hours' continuous test, while the overload test lasted 30 minutes, and took place after the above-mentioned 24 hours' working of the engine. The fuel used was a low-grade thick Californian oil of only 17·741 B.Th.U. lower value, the flash-point 185° F., and the gravity 0·948. The viscosity was 129·3 Engler at 20° C.

TABLE 9.

Tests of a 300 B.H.P. Horizontal Diesel Engine made at Hanover.
4-Cycle, 4 Cylinders.

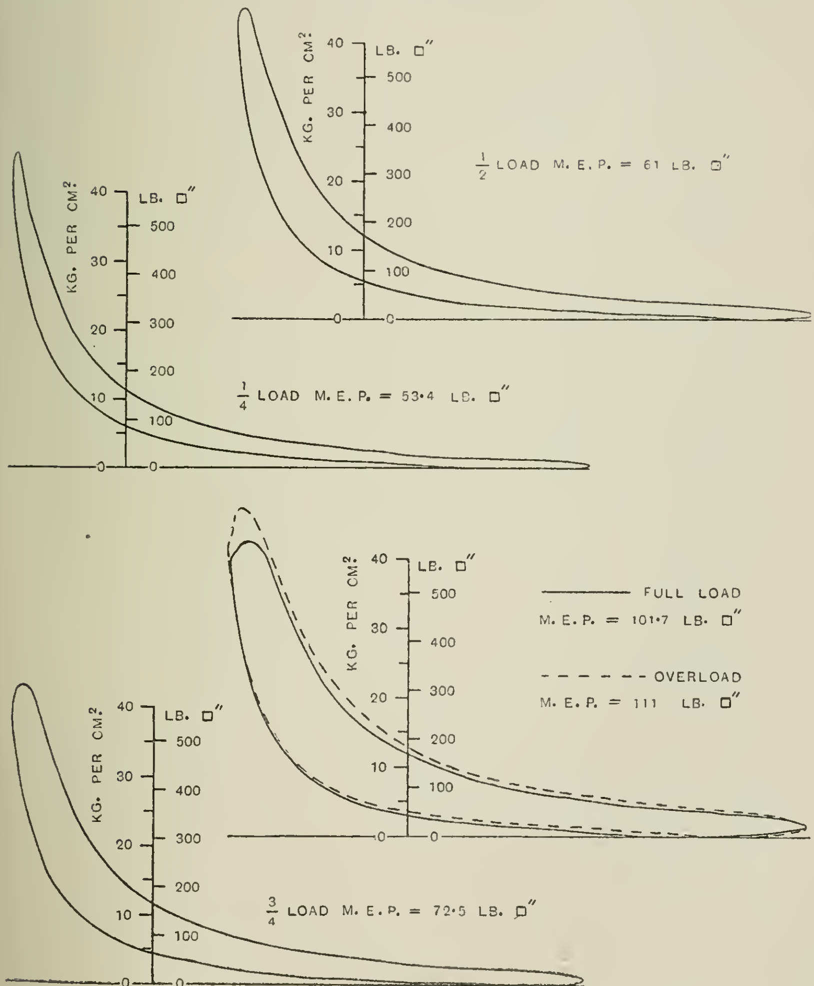
Annexed to the Report of M. R. E. Mathot, 5th June, 1914.
Diameter of Cylinders D = 14·2 inches.
Stroke of Pistons S = 26·77 inches.

Load factor.	Full.	Three-quarters.	Half.	Quarter.	Over-load.
Weight on brake L = 2·53 m. Kg.	473·6	356·8	236·9	119·5	568·0
Revolutions per Minute . .	181·7	183·1	184·4	185·3	180·2
Brake Horse-Power . . .	304·75	231·25	154·7	78·4	362·3
Average M.E.P. . Lb. per sq. in.	102	85	64·5	49·8	121
I.H.P.	398·4	332·76	257·5	200·0	471·8
Mechanical efficiency . Per cent.	0·76	—	—	—	0·76
Thermal efficiency for B.H.P. .	0·36				
,, ,, ,, I.H.P. .	0·475				
Initial pressure on Piston . Lb.	596	582	568	582	603
Cooling water Cylinder head temp. of outlet . . F°	140°	131	131	140	
(Inlet 95° F.) Cylinder . F°	167°	154	149	149	
Fuel-oil per B.H.P. hour . Lb.	0·388	0·385	0·439	0·577	
Number of revolutions without load	187				
Mean compression pressure .	465 lb.				

Revolutions Variations with Sudden Load Variations.

	Revolutions per Minute.			Duration for Settling.	Variation.
	Maxim.	Minim.	Settled.		
From—				sec.	per cent.
Full to quarter load	192	182	184	18	5·4
Quarter to full load	182	172	128	20	5·5

Fig. 14.—*Indicator Cards from Tests of a 300 B.H.P. Horizontal Diesel Engine. 4-Cycle, 4 Cylinder.*



Professor F. W. Burstall wrote, in reply to the written communications, that Mr. Benton was no doubt correct in supposing that only a thin layer of hot gas was in contact with the wall, and that the core of the charge was but little affected by wall action, especially in the small high-speed motors.

M. Mathot was somewhat severe in his remarks to the small size and low efficiency of the small Diesel engine; no doubt it would be an advantage to have tested a larger engine as bearing more nearly on commercial work, but the engine had to be used, or none at all. Far from being out of date, this small engine was a very fine one, and one could not see in what detail the inferiority came in, apart from mere size.

It must be borne in mind that the Paper was a scientific one, dealing with the behaviour of hot gases expanding in contact with metal surfaces, and its main merit lay in the care and accuracy of the results; the fact that the efficiency was a few per cent. lower than the maximum possible was of no importance in the scientific value of the results.

M. Mathot's test figures of a 300 h.p. Diesel engine were of great interest, and would be of value to those members who would want to know what could be done by means of a high compression; from similar engines the writer would consider that a compression of 465 lb. would mean an air injection-pressure of nearly 1,400 lb., which was certainly high for a commercial engine.

The writer would point out that if the prime mover of the future was to be an internal-combustion engine, as seemed probable with high fuel costs, the oil-engine would always labour under the defect of a narrow field from which oil could be obtained, and for this reason alone the gas-engine was the only serious rival of the steam-turbine.

THOMAS HAWKSLEY LECTURE.*

THE GAS ENGINEER OF THE LAST CENTURY.

By HARRY E. JONES, *Member*, of London.

Dr. W. Cawthorne Unwin, F.R.S., *President*, in the Chair.

Friday, 3rd *November*, 1916.

Introductory.—Before commencing this Lecture I desire to say that I consider it a privilege to be allowed to deal with a branch of the history of the "Giant Age" of the nation's Engineering progress during the past century. If this term appear extravagant, I would ask consideration first, for the problems that the Engineers of the day had to solve and, second, for the entire absence of skilled and experienced contractors to furnish the means of meeting their solution, coupled with deficient or bad transport in the dawn of the railway and canal systems.

To-day, with the wide and fuller extent of experience, these difficulties have largely disappeared, while the facilities afforded for meeting them have greatly increased by the advance in machinery for construction of plant and in the skill of the necessary workers in all the metals and building materials on the largest scale, due to modern inventions. To-day, plant, implements, and machinery of the most microscopic delicacy and efficiency are found everywhere, while even the largest of the enormous constructions necessary are well within the scope of the average practical builder and contractor.

* *First* Thomas Hawksley *Lecture*, by E. B. Ellington, Proceedings, I. Mech. E., 1913, page 1215. *Second Lecture*, by W. B. Bryan, 1914, page 811. *Third Lecture*, by Dugald Clerk, D.Sc., F.R.S., 1915, page 591.

Thomas Hawksley.—The subject personality of this Lecture presents at once a powerful and picturesque figure among the early pioneers of the Engineering profession prosecuting the industrial progress of the country in transport, mechanical production, cultivation and, not least, provisions for the sanitation, convenience, and comfort of the population in all directions.

I propose to follow the maxim: "ne sutor ultro crepidem," and to illustrate, as far as may be, from personal records and experience, the history of the progress in the special industry of gas lighting and to trace and compare the careers and duties of a Gas Engineer of Mr. Hawksley's day with those of the present. He was, like all the early Engineers, a *general* practitioner. Not only did he improve the health and brighten the homes of the masses in our great towns by his imposing and monumental works of water supply, followed up by the consequential development of sanitation by sewage works —only possible where adequate water was already provided—but he further practised extensively in the installation of gas supply which, originally confined to Lighting, soon expanded in the direction of Heating, Power, Ventilation and the numerous uses to which it has grown to-day, so that he is linked insolubly with the history of coal-gas.

It will be informing and interesting to consider the Engineer's work, its responsibility and its difficulty in this branch, in the early part of the nineteenth century, when little was known of the necessary requirements in plant and the methods of applying them, and practically nothing of its special operations for purifying.

No Contractors.—Contractors did not exist for the specialities as they do to-day, and the Engineer necessarily had to furnish drawings, specifications, and workshop instructions in the fullest detail. Moreover, for the section work on furnaces, retorts, purifying plant and storage, as well as for the installing and carrying on the operations essential to the construction of the sections, methods had to be devised, and the contractor and his workmen had to be instructed in them in a degree beyond the understanding of Engineers and Contractors of the present day, who have had all the benefit of their predecessors' experience for

the three generations which have passed. It will be seen that the Engineer had much more to devise and to superintend than at the present time, when so many standard examples exist and when competent contractors are found in any number all round.

Personal Instruction of Artizans.—I would guard against being understood to suggest that essential elements in design and execution are even now to be in any degree passed over by the Engineer. I am referring solely to the fact than when the Engineer had completed his drawings, specifications, and his estimates, he had to ensure, by circumspect and close supervision, and indeed, practical instruction, how the work was to be done in detail by the artizans.

History of the Gas Industry.

I proceed now to a review of the history of the gas industry down to the present time, illustrated in a measure from personal experience. It is hoped this may be of some interest to the Institution of Mechanical Engineers, of which I am proud to have been a Member for nearly forty years.

As coal-gas was born with the last century as a practical illuminant, though experimenters had found it in the Chemist's laboratory in the preceding century (by Clayton, Dean of Kildare, and Bishop Watson of Llandaff), it is worth while to see what need there was for it, who were the Engineers who practised in it, what difficulties were presented to them, how they surmounted them and what progress followed their work; and later to see what is the position and what should be the aim of the Engineer to-day.

As to the need for a cheap illuminant we have no record of the prices of illuminating materials at that day, but, judging by the comparative costs given by Dr. Ure, as late as 1841, namely, tallow candles (dips) 8*d.* per lb., wax candles 2*s.* 6*d.* per lb., and sperm oil 9*s.* per gallon, we may be sure that in 1805 gas had even more costly sources of light to compete with.

The invention of *practical* gas-making, due to Murdoch in England and claimed by Philip Lebon for France, took shape in the lighting of Murdoch's own house in Cornwall in 1792 and of

the Soho Works of Boulton and Watt in 1802, the further lighting of London streets in 1804 by Winsor, followed by Parliamentary schemes of 1809–10–12–14 for the National Light and Heat Company, afterwards the Chartered Gas Company, now the Gaslight and Coke Company of London. The plans submitted to Parliament by Winsor were very crude, and Plate 5 shows the square gas-holder, condenser in tank, hand-power purifier, and first part of London lighted.

The lighting of Paris streets, by Lebon, followed in 1815. Winsor's schemes prospered in the hands of Clegg, Malam, and other prominent engineers, and by 1827 the whole of the public oil lanterns in London were replaced by gaslamps.

Peckston's Account of the Chartered Gas Company.—By the year 1823 the growth of plant to meet the advancing demand can be judged by Peckston's illustrations* of typical retorts, condensers of vertical pattern, group of four purifiers with valve, larger gas-holders and the telescope addition, Fig. 3, and his account of the Chartered Gas Company, which records three gasworks (Westminster, Brick Lane, and Curtain Road) collectively producing two-thirds of a million, say 660,000 cubic feet of gas daily, and supplying 30,000 burners—probably Cockspur Jets. These works used 911 retorts and 33 gas-holders, of which 15 were at Westminster, 12 at Brick Lane, and 6 at Curtain Road, and which must therefore have averaged only 22,000 cubic feet each.

This Company alone more than equalled the sum of the three others then operating in the heart of London, namely:—

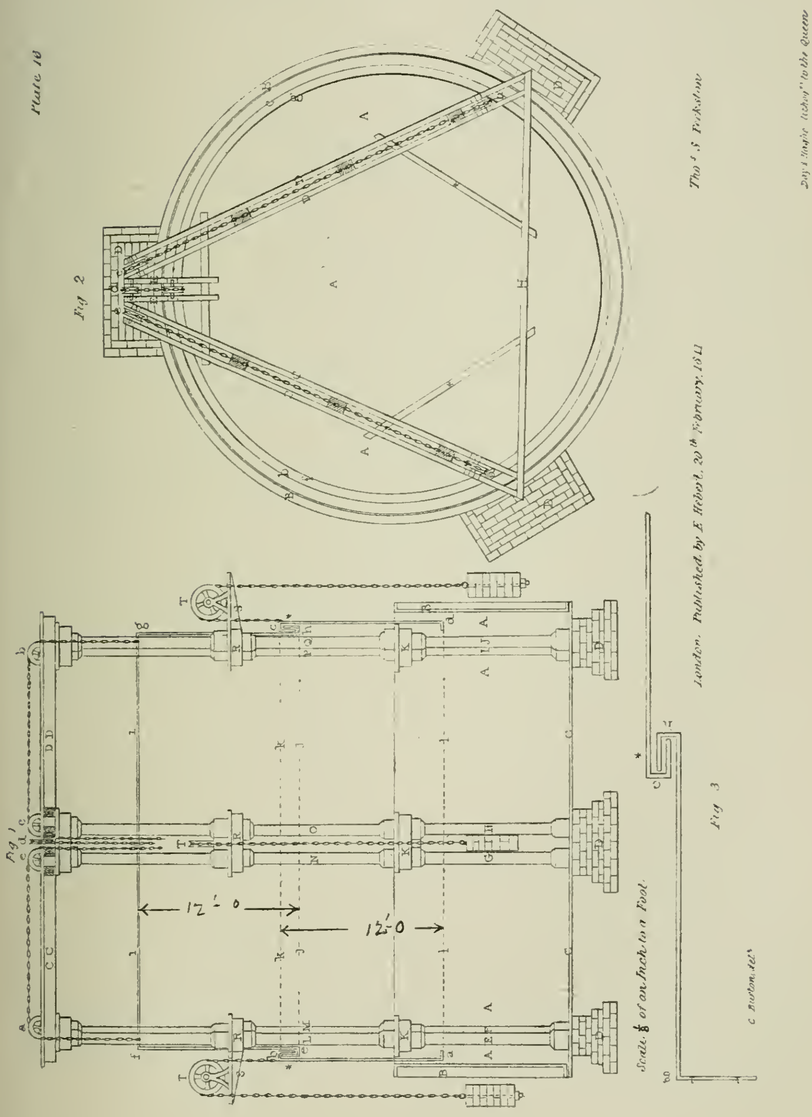
(1) The City of London Company, founded in 1813, at Blackfriars, which at one time had works at Aldgate fitted with Clegg's collapsible bellows holders.

(2) The "South London," afterwards the Phœnix, Gas Company with works at Bankside and at Vauxhall Bridge; both perpetuated in existing works.

The whole of these were only equal to one-fifth of the consumption already secured by the then Chartered Gas Company, as just stated.

* "Practical Treatise on the Manufacture of Gas," 1841.

Fig. 3.—*Gas-holder. Capacity* 17,500 *cubic feet*, 32 *feet diameter.*
(Photo from the original engraving, "Practical Treatise on the Manufacture of Gas." Peckston. 1841.)



The price of gas was in the neighbourhood of 15*s.* per 1,000 cubic feet, calculated by the number of single jet lights (cockspurs) consuming 1 foot per hour.

There were no meters, though at the works the filling of the holders was indicated and recorded.

In outer London, the Imperial Gas Company, founded in 1813, had works at Hackney Road, which are continued by works now in existence, denominated the Haggerston Station. The 6 holders at that station were only of 10,000 cubic feet content each, which contraction of scale was due to the popular alarm, which limited the contents of any single holder to about this quantity. Gas was then looked upon as a dangerous explosive in itself, apart from the admixture of air now known to be necessary for its explosion. It was indeed proposed by learned Societies that holders should be limited, and further, that they should always be enclosed inside buildings.

Ratcliff Gas Company.—In the same year of 1813 the Ratcliff Gas Company was founded, incorporated in 1823, and later merged in the Commercial Gas Company.

East London Gas Company.—There were also small works at this date, owned by the East London Gas Company, for supplying Mile End, of which there are traces at the Johnson Street Gasworks of the old Ratcliff Company.

British Gas Company.—There were, further, works at School House Lane, Shadwell, belonging to the British Gas Company, which had works in other parts of the Kingdom. These works became absorbed by the Commercial Gas Company about the year 1852. There were also gasworks at Millwall belonging to the Poplar and East London Gas Company. These works were also absorbed in the early "Fifties" by the Commercial Gas Company.

At this date there was a great predilection for gas made from oil, and in addition to the small works at Aldgate, which later became the property of the City of London Gas Company, there were some works for the supply of Stratford in existence on the River Lea at Bow Bridge. These were absorbed by the Commercial Gas Company.

Small Increase of Gas Consumption.—But with all the above works, the total annual London consumption of gas had only grown by the year 1837 to some 1,600 millions cubic feet, showing the moderate advance of about 60 per cent. in 14 years. By 1848 the consumption of gas in London had doubled this, amounting to 3,200 millions, and requiring at 9,500 cubic feet per ton, some 355,000 tons of coal. The average price of gas at this time was 6*s.* per thousand cubic feet for private consumption and 3*s.* 10*d.* for public lighting.

To deal with this business in London, there existed no less than 13 gas companies, the dates of incorporation of which are given in the accompanying Table 1; but it must be borne in mind that in nearly all cases they were founded several years earlier than the dates of incorporation. They carried on their operations with a good deal of rivalry and contest, being allowed to open the roads by the indulgence of the various Local Authorities, who, in fact, did not appear to have been aware of the rights, if any, which they had to prevent the unauthorized operations.

TABLE 1.

Dates of Incorporation of 13 *London Gas Companies.*

Chartered	1810	South Metropolitan	1833
City of London	1819	London	1833
Imperial	1821	Commercial	1836
Ratcliff	1823	Great Central	1849
Phœnix	1824	The Western (Commercial Gas)	1848
Independent	1824		
Equitable	1830	Surrey Consumers	1851

Meanwhile, by the year 1847, so much activity in prosecuting gasworks had been shown all over the country, that Parliament found it necessary to pass a General Act, to be incorporated in the future with all the private local Acts, which, while conferring privileges as to the opening of roads and bridges, etc.—all subject to satisfactory reinstatement—regulated the proceedings and administration of the undertakers both financially and commercially on definite general lines.

The growth from this time in London is shown on Table 2, being an advance, between 1837 and 1915, from 1,600 millions to 42,624 millions cubic feet in the 78 years, with the average price of gas

TABLE 2.

London Gas only.

(From *Peckston* and earlier to 1869, and from *Field* 1869 onward.)

—	1837	1849	1869	1879	1889	1899	1909	1915
Coals used (tons)	—	—	1,171,588	1,870,000	2,678,000	3,195,500	2,992,000	2,866,775
Gas sold (millions)	1,600	3,200	9,885	17,635	20,649	34,057	38,300	42,624
Price (average) .	6/–	6/–	4/–	3/6	2/5	2/2	2/2	2/8·4
No. of Consumers per Mile of Main . . .	—	—	—	—	105	178	278	306
Gas sold per Mile of Main (1,000's)	—	—	—	—	8,906	10,469	10,327	10,050

reducing gradually from 6*s.* to 2*s.* 8*d.* The number of consumers per mile of main grew from 105 in 1889 to 306 in 1915, and the sale per mile of main from 8,906,000 cubic feet to 10,050,000 cubic feet in the same period.

These figures show in recent years how the general population has increased its use of gas, as distinguished from that formerly used. It is largely due to the introduction of the working-man's Slot-Meter.

Turning now to the progress throughout the country at large. Beyond the list published by the *Journal of Gas Lighting* in the early years of its issue (1849–50) in which there were no fewer than 750 established gas companies in the Kingdom, there are no records available of the general position throughout England and Wales, Scotland or Ireland, before 1880, when the Board of Trade collected Returns and published them by order of Parliament; the leading features of which are shown on Table 3 (page 640).

From Table 3 it will be seen that in one generation (35 years):—

> The Capital has increased 224 per cent.,
> Coal used has increased 170 per cent.,
> Gas consumed has increased 300 per cent.,
> Number of Consumers has increased 500 per cent.,

and as between 1890–1914 the extent of mains was only increased by 80 per cent., namely, from 21,970 to 39,100 miles, it is clear from this disproportion there was an increasing use over the same areas. The sale per mile of main rose in 24 years from 4·3 millions cubic feet to 5·4 millions, and the average per consumer fell from 41,000 to 23,000, showing the largely extended adoption by the poorer classes.

Looking to the competition from electricity in the lighting branch, the increase shown in number of public lamps, from 286,300 to 741,703 (of which 20,918 fell in the last four years of the Return), does not seem as if, for economically lighting the largest areas, gas was going out of use.

According to Dr. Ure, published in 1841, the ton of coal was computed to produce:

> 9,500 cubic feet of Gas,
> 13½ cwt. of Coke,
> 12 gallons of Tar (showing low heat of retorts), and
> 10 gallons of Ammonia Water (which would have been of a strength of about 12 oz. to the gallon)

TABLE 3.

Particulars from Board of Trade Returns as to Growth of the Gas Industry throughout the Kingdom.

Year.	No. of Authorized Under-takings.	Capital paid-up and borrowed.	Tons of Coal Carbonized.	Gas Sold (1,000's cubic feet).	Length of Mains. (Miles).	Number of Consumers.	Number of Public Lamps lighted.	Sale of Gas per mile of main (1,000's cubic feet).
		£						
1880	not given	43,400,000	6,081,000	52,000,000	not given	1,530,000	286,300	—
1890	594	61,344,357	10,242,427	94,645,613	21,969½	2,297,278	460,384	4,308
1900	693	102,924,220	13,906,288	140,418,454	27,591	3,713,289	605,156	5,090
1910	809	134,683,695	15,397,783	182,833,928	36,122	6,417,849	720,785	5,062
*1914	834	139,727,277	16,684,087	210,907,376	39,100	7,298,007	741,703	5,402

* Latest available Returns.

About this date (1839) a curious Estimate was put out by J. Hedley, from Sheffield and Dublin, for Profit on Gas Supply. A ton of coal, costing 17*s.*, produced for sale:—

	£	*s.*	*d.*
8,500 cubic feet of Gas @ 9/-	3	16	6
12 sacks of Coke at 1/-	0	12	0
19 gallons of Tar @ 2½*d.*	0	3	11½
	£4	12	5½

Services to consumers' houses were originally of lead, as for water supply. These were superseded by old gun-barrels screwed together, until in 1825 Whitehouse brought out a patent of Russell's, dated 1817, for cheaply made tube of greater length and uniform section of metal, welded by a patent process and screwed together by suitable sockets. For many years the term "barrel" was applied still to the new pipes, just as the expression "trunk mains" was taken, from water practice, to apply to cast-iron.

Only in 1830 did dry lime purifiers come into gradual use to supersede wet lime vessels, the nuisance from "Blue Biliy" being even greater than the dry lime caused; but the older system was still to be seen in 1854 at the London Gas Company's Works, Vauxhall.

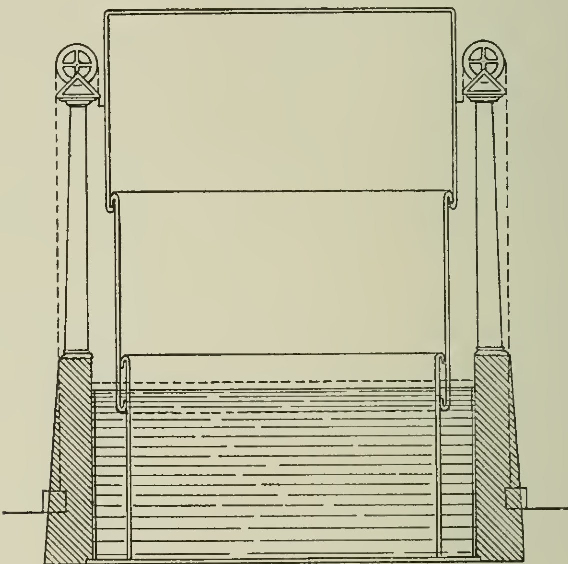
The bulk of the gas-holders were still only about 30,000 cubic feet capacity, though the Chartered Company's Engineer, Mr. John Evans, is said by Dr. Ure to have been contemplating one in a single lift 95 feet diameter by 40 feet high, containing 250,000 cubic feet, which, when compared with Sir George Livesey's great work of 12 millions, and the Birmingham holder of 6 millions, by the veteran Charles Hunt, only impresses one by the magnitude of the development over the intervening half century.

In 1822 the proposition for telescoping gas-holders, Fig. 4 (page 642), to save deepening the tanks was made by one, Tait, of Mile End, using similar water-luted grip to that used to-day, but the hydraulic cups were *internal* (where their condition as to leakage and as to the free working of rollers could not possibly be seen

or rectified). Fortunately the engineers of the day rejected the suggestion. The use of similar grips or cups, placed externally, was later introduced by one, Hutchinson, having been applied at the City Gasworks in 1844, and this arrangement continues in use to-day.

During the craze for oil-gas, Godwin brought out a patent in 1819 for bottling it up in metal globular vases at high pressure, 20 to 30 atmospheres, and it was in carrying out this process that

Fig. 4.—*Telescopic Gas-holder* (*Tait*), 1822.



benzol was observed to be precipitated by Sir Humphrey Davy, who was consulted on the phenomenon. You know that to-day the duty has been placed upon gas undertakings to take benzol out of gas, as far as they can do so, and supply it to the War Department for war purposes. The whole amount of illuminating matter of that sort is only three per cent. in our gas, and whilst the removal of benzol does seriously alter the illuminating effect in a naked burner, it has very little effect, certainly not more than

four or five per cent. upon the heating power, which is the one that is realized in the Welsbach incandescent mantle. The proposition therefore to remove it is not a very serious one to the consumer, although it is of very great importance to the War Department. The patent was worked later by the London Portable Gaslight Company, but was soon superseded by the cheaper coal-gas owing to improved economy of distribution by cast-iron mains.

In Hebert's Engineering Encyclopædia, published 1841, there are shown designs for 3-throw compression pumps and for 2-wheeled carts to carry the gas in folding compartments constructed on the Bellows principle, of canvas, from which the bottles kept at the houses were to be filled. The companies formed for this sort of portable gas supply, however, rapidly came to grief.

As above stated, oil-gas was started at Aldgate for the supply of Whitechapel, but soon came to an end. An oil-gas works for Stratford also failed, and was taken over by the Commercial Gas Company in 1852. The predilection for compressed oil-gas arose in consequence of the cost and difficulties in the distribution of coal-gas, which are specially lamented in the preface to the Memoirs of Samuel Clegg's early working, elsewhere mentioned. The pipes were scarce and dear at £14 per ton, and the jointing was very imperfect.

Plant Development.—In the development of plant there were gradually introduced materials and forms less crude and more economical and convenient, gradually leading to those we are accustomed to see employed to-day on the enormously increased scale necessary. A striking illustration of the structural advance in scale and methods is furnished by the design of a gasworks for 1 million cubic feet per day, by Jos. Hedley, of Dublin and London, published in 1845 by Dr. Ure, Fig. 5 (page 644). It is remarkable for the multitude of units of purification and storage and their crowded position, with inadequate working spaces for coke and materials, there being 12 gas-holders of only 83,000 cubic feet capacity each, and 12 purifiers, for 1 million feet of gas per diem, whereas to-day 3 purifiers suffice for 4 million cubic feet per diem.

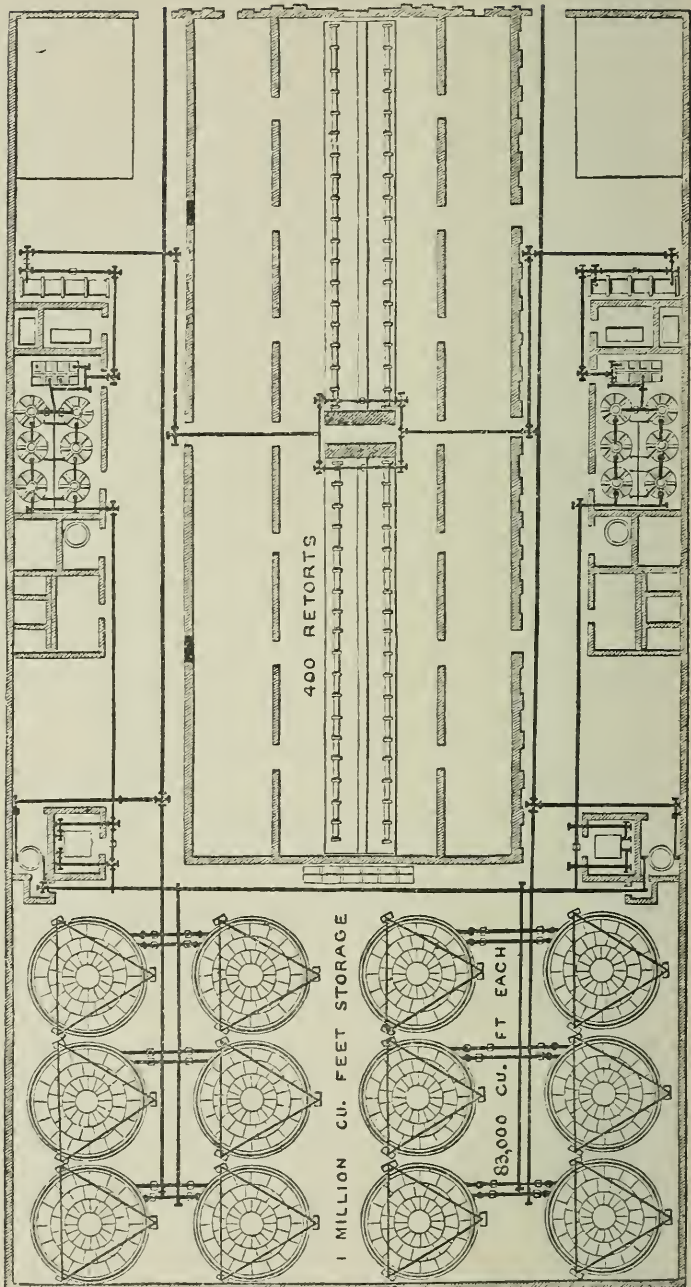


FIG. 5.—*Design of a Gasworks for 1 million cubic feet per day.*
(Photo from the original engraving in "Ure's Recent Improvements in Arts and Manufacturers." Jos. Hedley. 1845.)

In the earlier days cast-iron retorts of circular, oval and kidney section were generally used in carbonizing. About 1820, clay retorts were introduced and used by Fraser in Scotland and by Grafton in England, but were not generally used in England till after 1840.

Retorts of fire-clay, though obviously more refractory and enduring than the expensive heavy cast-iron retorts previously used, cost, by Clegg's treatise, upwards of £20 per ton; nevertheless, owing to the porosity and liability to crack and gape when cooled down in the necessary periods of idleness, were very little in favour, and did not come into exclusive use until after the year 1850, when the perfection of the exhausting plant enabled them to be worked under very low back-pressures, saving the waste by leakage and the choking by deposited carbon, that made their use in careless hands more precarious and expensive than it need have been. So late as the year 1864, iron retorts were used by Croll and George Anderson, in settings where the primary hot gases of the furnace were directed to clay retorts set above the iron retorts, and these were drawn when reduced in temperature round the iron retorts below. This system claimed especially to save fuel, and was successfully worked for many years both at the Surrey Consumers and the Great Central Works.

For the conservation of heat, retort benches came to be placed with the furnaces back to back, leading ultimately to the retorts being made continuous, of double length, with duplicate mouthpieces and ascension pipes. This facilitates cleaning off the carbon deposited owing to their porosity. The loss by leakage and the excessive deposit of carbon were cured ultimately by Grafton's invention of the exhauster, by which internal pressure was relieved from the retort and the gases removed as fast as made. Fraser in Scotland, John Eunson and Robert Jones in the Midlands and in London in the "Forties" and "Fifties," did much to establish the durability and the superior efficiency in carbonizing of the clay retorts, in early days, while both A. Croll and G. Anderson were great and persistent advocates of the value, in more recent times, from 1845 onwards.

The furnaces for heating retorts have undergone important

changes since the Siemens' reverbatory furnace for smelting was invented. This was proposed in 1863 for a gasworks scheme in Birmingham. Mr. C. Hunt, in Birmingham, gave great attention to the new system, as did Hyslop in Scotland, and we are indebted to the labours of both these gentlemen for the early steps leading to the present success which gives great control of temperature as well as saving of fuel.

Machinery.

Modes of Charging Retorts.—Gradually, to save cost and the strenuous and excessive labour of charging retorts on a large scale, there has been introduced machinery, which in the early stages took first the form of a machine with a number of scoops such as had previously been handled by workmen, projected into the retort, imitating the precise action of the workmen. These machines were soon abandoned, as the wear and tear and power costs were excessive.

The next machine was one introduced by Mr. Robert Morton at the London Gasworks, for employing steam-jet propulsion of coal in successive parcels into the retort in the manner imitating the shovel charging of earlier days. This again gave way to the hydraulic machine, the best of which is still to be seen working in many gasworks. The Arrol-Foulis, due to the combined ingenuity of the late William Foulis of the Glasgow Undertaking, and Sir William Arrol, was introduced. For low wear and tear and steady action these machines are not easy to beat to-day.

An extremely successful and economical plant is the West system of charging, the power being given by compressed air. It is working to-day with the greatest efficiency at several gasworks in London. The inventor of this system, Mr. West, was formerly the engineer of the Maidstone Gas Company, and his plant, always combined with a very efficient retort setting on the regenerative principle, is successful wherever applied. An economical machine is the French DeBrouwer, which projects the coal into the retort without introducing any mechanical parts of the machine into the

retort itself. It is widely used on the Continent and extensively in this country. A later machine is the Fiddes-Aldridge, which takes the coal, by articulated sections of the machine, into the retort, and at the same time pushes out the exhausted coke. This machinery is gaining ground. With all these systems the coke is expelled by mechanical pushers, avoiding the tedious and exhausting labour of drawing by hand-rakes.

Machinery.—These operations of retort charging and discharging, coal elevating and trimming, are to-day performed by machinery for labour-saving motives. This, sometimes driven by hydraulic pressure, sometimes by compressed air, is latterly most frequently performed by the distribution of the power of gas engines through electrical current. It is fair to say that in these ways, while the cost for labour has been reduced by 30 to 35 per cent., there is an addition of at least 25 per cent. to the wear and tear charges. A very important advantage of machinery is the even progress of the operations and its being less liable to the variations always arising from the human element, and another, that the type of labour essential to be used with machinery is of a more intelligent and responsible class.

On the question of labour generally, the introduction of the Livesey Profit-Sharing has very much improved the service, as the men rapidly realize the greater independence and stability of their position, especially when they have become investors in the Undertaking which employs them.

At the present day efforts are being made to produce a better coke by carbonizing the coal in ovens on lines approaching that of the coke-producing plants working at the various collieries. These are not new ideas, as the old London Gas Company had, in my own memory in 1854, ovens for making gas and coke on a principle such as is now suggested and indeed in use at Birmingham. They were introduced by M. Michele, a French engineer, but they were ruinously inefficient, chiefly through bad construction, and the company were working without profit until, on the death of Michele (who was killed whilst making experiments with benzol), the Company consulted the late Robert Jones of the Commercial

Gas Company, who replaced the ovens by clay retorts on his system (which is illustrated in Samuel Clegg's Manual). The Company were in a few years paying a dividend of 10 per cent. in consequence of the change to retorts.

There have been successively introduced, to displace the horizontal retort, the inclined system (the invention of M. Coze, of Rheims), which has been widely used, and at the present time, a great development of a system which employs the force of gravitation even more effectively, that is, the vertical retort brought out originally by Mr. Harold Woodall of the Bournemouth Gas Company. This invention, perfected and worked out by the collaboration of his partner, Mr. Duckham, has been widely and successfully applied. There are a great many modifications of the system being introduced, and they are favourably reputed; but so effective has the carbonization been found of a good regenerative system of furnace and thoroughly efficient machinery for charging, as to preserve still the original horizontal system, though with modified furnaces and fittings.

Condensers, generally of extended lengths of ordinary cast-iron pipes returning by bends or coils so as to be drained into tar-collecting wells or cisterns, were successively introduced by Malam in 1817, George Low in 1839, John Kirkham near the same time, Marten of Perth, and later, Alexander Wright of Kensal Green. But the saturation of the condensed liquor with ammonia, sulphur, carbonic acid, and sulpho-cyanide being desired, the tubes of a condenser are now arranged horizontally rather than vertically. On the older plan the rapid separation of the ammoniacal water removes it whilst too hot to be capable of exercising its full affinity for the impurities. It is now further sought to cool the gas more gradually, and always in contact with both the liquor and tar. Therefore, the contact is now extended by making them flow together as long as possible, always avoiding sudden changes of temperature, which with the vertical pipe condenser cannot be prevented. Usually, to-day, the condenser pipes are either staged or suspended so as to incline slightly from the horizontal, keeping the liquids flowing along with the gas.

Purification.

For the first 50 years of the last century the purification for ammonia was not much practised, but gradually the value of the product brought its extraction into almost universal use. The apparatus employed was originally vertical scrubbers of cast-iron, in which a counter-current stream of water met the flow of gas.

A different form of plant, being a rotating screen working in water through a large horizontal cylinder, originated in the invention of Mr. Paddon of the Brighton Works, and is still to be seen there. His plan, with extensive modifications, has been widely used since. It remains to be said, however, that the earlier form of plant has great simplicity and freedom of working parts to recommend it, and has completely met the most searching tests of efficiency.

Purifying was carried on by lime in water vessels down to 1858, when they were to be seen at the old London Gas Company's works near Vauxhall Bridge. (These works were interesting, as they were constructed on the grounds and park of the original Vaux Hall from which the Gunpowder Plot was directed by Guido de Vaux.) But purifying by hydrated lime in a dry condition had been introduced gradually for many years before this time. Patents were taken out at various dates for purifying by oxide of iron instead of lime, and so avoiding nuisance. This process is now almost universally applied, with the advantage of recovering the sulphur for acid-making.

For the removal of ammonia, Croll brought out a patent for its elimination by chloride of manganese, but this was not only expensive and required commodious plant, but it was less effective than the system of washing and scrubbing by water now universally practised.

Great economy and efficiency is gained by the provision of sufficient surplus cubic capacity for purifiers, so as to provide not only for the incremental growth from year to year, but to avoid back-pressure and to secure a lower speed and longer contact with the gas. The ordinary rules of half a square foot of area per 1,000 cubic

feet per diem in each vessel on the series of the purifiers, and a slightly larger one, 0·6 square foot for lime in purifiers, can be exceeded with great saving of labour and increased efficiency of material. Nowadays, revivification of the material is almost universally secured *in situ*, avoiding much unnecessary labour in discharging and refilling the material into the purifier. Owing to the value of sulphur for the manufacture of sulphuric acid nowadays, it is possible, with a sufficient margin of area, to purify at practically no cost, but some small profit. With a view to economy, some Engineers, including myself, have constructed purifiers in concrete, sunk into the soil. Subject to special construction to avoid the leakage arising from a porous material, there is no real difficulty or objection to their employment.

Gas-holders.

Gas-holder Tanks.—Tanks of brickwork or masonry were proposed by one, Tunks, for gas-holders, and in this he no doubt was following the much earlier system of waterworks reservoirs. But cast-iron tanks of flanged plates were extensively used where foundations were bad, and these were only displaced by steel and wrought-iron plated work, which continue to be used for the smaller dimensions. For tanks on the scale now common for gas-holders, of from 2 to 10 millions, the water pressures demand such heavy sections as make the execution of them in metal very difficult and uncertain in efficiency, so that the larger works are carried out chiefly in Portland cement concrete, executed simply and rapidly in parallel vertical section in timbered trench work. They are made much shallower in proportion to diameter, to avoid cost of construction and, further, in some places, serious engineering difficulties, arising from penetrating water-logged strata of peat and running sand, through a better foundation. This was found by Sir George Livesey at the East Greenwich Works, and by Mr. Trewby at the Beckton Works, when they were digging to the depth that was necessary to carry the great holders that they installed.

Gas-holders.—The gas-holders themselves are often of from 3 to 6 telescopic lifts, and almost invariably without roof-framing

beyond the timber support on which they rest when landed empty. The adoption of multiple lifts in their construction gives scope for great economy, especially on large scales. The whole work of tank and gas-holder complete has been effected on a scale of 3 millions at the cost of little over £5 per 1,000 cubic feet, whereas such gas-holders as were contemplated in the illustration of Hedley, Fig. 5 (page 644), are known to have cost from £40 to £50 per 1,000 cubic feet.

Distribution.—The distribution of gas is carried on to-day through cast-iron pipes corresponding very closely with those illustrated in Winsor's applications to Parliament for his schemes. They were reported in Clegg's period to be costing £14 per ton, being of cold-blast iron. Probably they cost higher prices than these in Winsor's early day, so they must have been rarely used. The Water Companies at that date, for corresponding purposes, used largely the trunks of trees, hollowed out and jointed by metal rings. This water practice must have been for economy, because as early as 1668 the water fountains at Versailles were supplied by small cast-iron pipes, showing the earlier use of metal.

The pressure employed for distributing are now much in excess of those in vogue until quite lately. Though Parliament only insists upon a pressure of 6/10ths in the daytime and 10/10ths at night, of head of water, the needs of supplies compel the use of pressures of 40/10ths and 50/10ths head, and often more. This is not found to increase the leakage, as was formerly feared, showing that the modern system of main-laying must be very perfect.

Systems of distribution are now extended far into rural districts, much beyond the earlier practice, and though some of the more concentrated supply areas distribute so much as 11 and 12 millions cubic feet per mile per annum, there are areas connected with rural Companies in which not more than 1½ to 2 million cubic feet per mile per annum are distributed. The pressures used and the capacities of the pipes laid in modern times are much affected by the very large increase in the use of gas by the lower classes of the population for domestic purposes on the slot system, which by prevailing through the hours of daylight and extending

further through the summer period of daylight, goes far to level the peak of the load upon the various systems. Indeed, one of the distinctive marks of the recent progress of gas-lighting is this adoption by the working-man of gas in place of coal.

In the service pipes a heavier type of wrought-iron tubing has been gradually brought into use, such as is generally used for steam purposes. Where this is coated with pitch when originally laid, and is put at a suitable depth to protect it, especially under the waterproof road surfaces that are now in favour, it confers a very much longer life on this, which was formerly the most perishable part of the fixed plant of a gas undertaking.

To complete this branch of my subject, reference must be made to the perfection in the accuracy and in the improved substantial construction of the meters employed, the life of which again is considerably extended; possibly in some degree owing to the improved purity with which the gas is supplied, as against ancient days. Dry meters have practically displaced the wet system, except abroad and in India.

In 1850 the whole of the mains for the Great Central Gas Company were laid throughout the City of London, by stipulation with the Corporation, during the hours of night, the pavements being restored for use in the daytime. This has often suggested the avoidance of the inconvenience of paving repairs which are to-day carried out by the same Corporation in the hours of daylight. In London, in 1864, subways to contain gas-pipes were first of all used in Southwark Street, constructed by the then Metropolitan Board of Works. Pipes were laid in these by myself as a test case, the Engineers concerned for the Act of Parliament having been Messrs. Bramwell and Sir Joseph Bazalgette.

Carburetted Water-Gas.

From the "Eighties," carburetted water-gas plants came into use somewhat extensively, at first for enrichment purposes, eventually as auxiliary supplementary means of production for various emergencies and contingencies. In America the form of water-gas plant, on the principle identified with that tried by George Lowe

in the "Thirties," had been modified and applied to the exclusive lighting of communities, as it utilized the large production of the residual oil from the great wells, after the petrol spirit and the lamp oil had been distilled. As this oil was of low commercial value as a by-product, a very high illuminating power could be cheaply got by the generous use of it with water-gas, because for each gallon that was cracked in the superheaters a value in lighting of from 7 to 8 candles could be given to each 1,000 cubic feet of gas produced.

In England, the illuminating standards were quite above the potentiality of ordinary coals, cannel coal—then becoming scarce and very dear, besides furnishing little residual by-products—had to be used to large proportions: often 10 to 12 per cent. The introduction of the new plant to English gas undertakings, chiefly at the hands of the firm of Humphreys and Glasgow, was therefore welcomed, the more so as the then price in this country of the necessary gas-oil from America was in the region of 2*d*. per gallon. As the plant occupies a much smaller area and costs much less to install per unit of output, gives its output very promptly when used intermittently, and produces any quantity of gas required within the limitations of maximum scale to replace the dearer cannel-gas, it naturally sprung into favour. The flexibility and facility so enjoyed enabled the manufacturer to supplement suddenly, and in great volume, the supply from the ordinary process, and so met emergencies without calling upon storage accommodation. Moreover, it had the merit of turning to useful account surplus unsaleable coke, and in this way was convenient and profitable as enhancing the value of coke generally.

Further, for getting over the peak of mid-winter demand without calling for extra labour or extra supplies of raw material, as well as for clearing away the redundant output of coke due to the season, the plant was, and ever will be, of great value in the practical carrying on of gas supply. Unfortunately, unless heavily enriched with oil, the heat efficiency is much below that of coal-gas, while the price of the oil has so risen in later years (quite apart from the present War effect) that, looking to the modern standards

of calorific value and illuminating power, there has been little temptation to its use. The more general appreciation of the value of coke for trade and steam use is against the process, as is also the more constant demand for gas through the daylight hours, which largely dispenses with the need for storage, and so robs the water-gas system of one of its greatest advantages in saving capital outlay and space for works.

For producing raw water-gas the system known as the Kramer and Artz has been found very useful, but for meeting the necessary standard of calorific value it needs the addition of hydrocarbon vapour.

Inventors.

Let us now see who were the Engineers, Inventors, and Mechanicians who met the needs of the successive stages of the great development shown by the figures quoted on Table 3 (page 640). Three figures stand out prominently:—

Winsor.—Winsor does not seem to have been so much the Engineer as the promoter. He put up Accum as the technician in the evidence before Parliament for his Bills for lighting London, at first as the National Light and Heat Company, afterwards the Chartered Gas Company. Until 1813, when Clegg came into the service of the Chartered Company, no practical or financial success was obtained.

Samuel Clegg.—From the earliest date of practical construction of gasworks the name of Samuel Clegg recurs frequently in all authorities and is represented by such substantial patents and improvements in the plant necessary to work out the practical operation of the primitive and crude schemes promoted by Winsor, that he deserves considerable notice at our hands. He appeared to have had a thorough Engineer's training and practice. Up to 1813 he was working at Boulton and Watt's (no doubt in contact with Murdoch), while he seems to have assisted in putting up gasworks on a small scale in the years 1806, 1807, and 1809, under Murdoch. He was, moreover, recognized by the Society of Arts for his description and plan of plant for the supply of Akermann's

premises in London in 1812, for which he received the Society's Silver Medal. In 1813 he was appointed Engineer to the Chartered Company at their Peters Street Works. At these works he was assisted by Malam, whose name occurs later on in connexion with many useful works. While at Peters Street, Clegg was injured by an explosion in the purifiers.

In the year 1817 Clegg left the Chartered Company's service and afterwards was building works at Birmingham, Bristol, Worcester, Bury St. Edmunds, and in many other minor towns. In the year 1850 he was writing vigorously to the "Journal of Gas Lighting," vindicating his claim to the invention of the wet meter, which was being contested by his old associate, Malam. In that year he also supported Croll's application for Parliamentary powers for the Great Central Gas Company, and speaking of having established 40 gasworks of various scales. The latest record to be found of him is in the form of memoirs of his early works, published by his son, Samuel Clegg, Junior (who pre-deceased him), in three editions, 1841, 1853, and 1859 respectively, which forms a very valuable manual on gasworks construction and management.

The invention of the wet meter and of the hydraulic seal in retort mains, valves, purifier covers and gas-holders, are all credited to Clegg, and justly so. Though there were advantages in Malam's meter invention, it is clearly an improved adaptation of Clegg's earlier appliance. It seems very obvious, however, that the hydraulic seals in all these appliances were borrowed from the Chemical Laboratory, where the collection of gases experimentally was always made, as now, in bell-jars over a water cistern through which the pipe from the still passed, being turned upwards within the perimeter of the inverted dome; this was so converted into an inspirating gas-holder by being filled with water and inverted while covered with water. Lavoisier, in 1795, designed an experimental metal gas-holder working in a metal tank of water, which is practically the identical apparatus used in testing meters to-day, and contains the exact principle, in miniature, of the largest gas-holder works of the present day.

In regard to Clegg's general use of hydraulic seals, while modern pressures render the use of mechanical joints more convenient for meters, valves and covers of purifiers, etc., and for movable sliding chandeliers, it was found both by Sir George Livesey and by the Lecturer, that no mechanically-faced valve of large bore was so secure in preventing small leakages from contaminating the gas when purified, as a water-sealed diaphragm valve. On the other hand, the dry meter has almost invariably displaced water-sealed meters in Great Britain. In any case, Clegg's inventions and methods of meeting physical difficulties command our admiration, as they were very remarkable and their utility prevails to the present day. In 1817 he patented a collapsible gas-holder of flexible canvas, applied on the principle of the ordinary fire bellows. These holders are recorded as being actually in use at an oil-gas works in Aldgate for lighting Whitechapel, previously referred to. These bellows worked with the lower edges of the side boards in a water-tank. The difficulty of collapsing any flexible canvas or leather with gas in that way is perhaps not so difficult between the hinged sides as it is when you bring the bottom edges of the boards, the wider edges of the boards, together. There is nothing would adapt itself to the motion of the side boards and the valvular motion like immersing them in water, and these gas-holders stood over a tank of water in which these side boards were placed. Nevertheless it was a very ingenious idea of Clegg's, as the gas-holder question was a very difficult one in those early days, because it was far and away the most expensive part of the plant that engineers had to contend with. He further invented a rotary gas-holder working in a tank of water, and also a system of pot retorts slowly rotating over a furnace gradually bringing the coal to the hottest flame. The Gas Industry is clearly indebted to Clegg for most of the practical inventions which conduced to the early extension of the use of gas, and many of which are in general use up to to-day. A very interesting and important figure—in fact, he stands out pre-eminent in practical work of value for the first twenty-five years of the development of gas.

Malam, Clegg's old foreman and associate in both the Soho Works of Boulton and Watt and at the Westminster Gasworks of the then called Chartered Gas Company. He seems to have done a good deal of work in the provinces and in the north, where his name is still to be seen on old pieces of plant. Probably much of this at first was done under Clegg's superintendence, as Malam appears to have, like a number of other engineers, become contractor by force of circumstances. He patented in 1820 an improved wet meter, introducing the Archimedean screw into the shape of the four revolving chambers, which were divided similarly to Clegg's original patent for two revolving chambers. In 1822 he patented a lime purifier, and, later, various subsidiary improvements. He seems to have been quite a practical man and a sound engineer.

Mabon, a Scotch Engineer, appears to have done a good deal of work in Scotland and the north at the same period as Malam.

Sadler, in connexion with the Liverpool Gas, preceded the very notable Wm. King, uncle of the late Alfred King, and a grand-uncle of the present Wm. King, all three of whom carried the history of Liverpool Gas from its foundation to the end of the century.

Peckston, the author of the "Practical Treatise on the Manufacture of Gas," which reached a third edition in 1841, describes himself as responsible for some 12 different works, of which the chief was at Bury St. Edmunds; but he appears to have been largely assisted by Malam.

Grafton, a pupil of Malam's, practised in the "Forties" in the provinces, and was responsible in a large degree for the introduction of clay retorts, and of an exhauster to relieve pressure on them—which reduced leakage.

John Evans, believed to have been the father of F. J. Evans, and his brother George Evans, Engineers respectively of the Chartered and Brentford Gas Companies, followed Clegg as Engineer to the Chartered Company, having charge of the Westminster Works.

George Lowe, who followed John Evans about 1849, was an important figure among gas engineers, and was largely consulted

by them. He had a long connexion with the Chartered Company, and trained the sons of his predecessor, who had positions under him, at Brick Lane and elsewhere. He had a system for water-gas.

John Kirkham, father of the late Thos. N. Kirkham, played a conspicuous part in the conduct of the Imperial Gas Company, and specially of the Fulham Works.

D. Methven was for some time Engineer to the Commercial Gas Company, and later to the Imperial Works at Haggerston. He supported Croll's scheme for the Great Central Gas Company.

John Eunson, at Wolverhampton up to 1846, played a very useful and considerable part in the introduction of clay retorts. He had all the plant and furnaces for making them at the gasworks at Wolverhampton, where he was followed by Robert Jones. After leaving the Gas Company, Eunson practised in Wolverhampton as a Consulting Engineer, and at the same time manufactured and contracted for retorts. He went to Northampton Gas Company later, where he was followed by his son.

E. Goddard, of the Ipswich Gas Company, had a long and valued career with that Company and as a Consultant. He was one of the pioneers, with Alfred King of Liverpool, in demonstrating the service of gas for domestic uses.

The brothers *Charles* and *George Robinson*, Engineers respectively of the original Gas Companies of Leicester and Coventry, were connected professionally very widely. They were acting for the Belfast and other important Companies. They were early pioneers in tar distilling at both Leicester and Coventry, and demonstrated its value; but the general run of undertakings, on even larger scale, neglected to follow them, and the trade in general went to outside contractors.

Bartholomew is a name associated with the earliest history of gasworks in Glasgow, but one fails to find particulars of his work or of those who immediately followed him.

Glasgow gas will ever be associated with the name of *William Foulis*, who reconstructed the original works for the Corporation, and added at least two very important new works on new sites, which are conspicuous for their good placing, efficiency in operation,

and low cost. The low selling price of gas in Glasgow is largely due to the skill and care of this talented Engineer, who was prematurely cut off. He was a student under Rankine and Lord Kelvin.

There are records of the name of *Reid* in connexion with the early history of the Edinburgh Gas Undertaking. This undertaking was bought by the Corporation, as was also the Leith Gas Undertaking, and the supply is now carried on by a large works at Granton, designed by W. R. Herring.

F. J. Evans followed G. Lowe in 1837, and remained all his life with the Chartered Company, afterwards the Gaslight and Coke Company. He advised and laid out the extension of older works, and ultimately their removal from London to Beckton, where he designed and executed those enormous works up to the date of his retiring and becoming a Director of the Company. It was an immense piece of work, and he was well advised to call in the aid of an independent Civil Engineer, Vitruvius Wyatt, who acted with him, and continued to act for the Company after Mr. Evans retired. These works are so large and important that they cannot be described here beyond stating that to-day they are equal to an output of 60 million cubic feet per diem, or 12,000 millions per annum.* Many serious engineering difficulties had to be met in foundation work, owing to the construction being on what had formerly, no doubt, been the bed of a prehistoric river delta.

George Evans, a brother of F. J. Evans, was largely identified with the foundation and progress of the Brentford Gas Company, which from comparatively small beginnings has grown into a Company third in importance in connexion with the Metropolis.

Robert Jones, at Chester in 1840, afterwards at Bath, in 1846 at Wolverhampton, and later at the London Commercial Company, was standing Consulting Engineer for many years of the London Gas Company, whose works at Nine Elms he originally laid out and constructed. Later, he was Consulting Engineer to the Surrey

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* *See* Proceedings, I. Mech. E., 1886, page 422, and Plan of Works in Detailed Programme, 1886.

Consumers' Gas Company, having works at Rotherhithe, a lease of which was surrendered to A. A. Croll, Esq., about 1855. He built the new Poplar Works of the Commercial Gas Company, 1876, which for economical expenditure of capital was always held by the late Sir George Livesey to be a prominent example. He reconstructed the Stepney Gasworks of the same Company. He was also consulted widely in the south of England, acting for many years for Chester, Leamington, Canterbury, Ramsgate and, in early days, the Wandsworth and Epsom Companies. Perhaps one of the most important of his consultative works was his negotiation for the Corporation of Birmingham for the acquisition, without arbitration, of the old Birmingham Gas Company's Undertaking, and the still larger one of the Birmingham and Staffordshire Company.

In his day Robert Jones led the way in large gas-holder construction at Stepney, where his holder for 2 millions cubic feet, afterwards increased to 3 millions, was at the period of its construction, in 1863, the largest known. He was a pioneer of high-temperature carbonization, such as to-day is represented by his successors and descendants in the very successful results obtained in the Companies that he specially directed. He paid great attention to the manufacture of clay retorts, which he carried on for the Wolverhampton Company. He established at Wolverhampton, about 1850, a private tar distillery and sulphate of ammonia works, in default of persuading his Company to take that step. He was, further, a pioneer in accepting the Sliding Scale Legislation for the Commercial Gas Company, which has operated with extraordinary success, that Company charging, at the present time, the lowest price for gas of the Central London Companies. He was a great admirer of Mr. Thomas Hawksley, and often conferred with him.

Alexander Wright.—Associated with London gas, as largely responsible for the Western Gas Company's Works at Kensal Green, is the name of one, Palmer, but the chief part of the works as existing in modern times, was the work of Alexander Wright, who was a man of considerable attainments. He was identified

with improvements in gas-meters and also in photometric and testing apparatus. He was for some time, also, responsible for the administration of the Great Central Gas Company, whose works are at Bow Common.

A. A. Croll.—Alexander Angus Croll, assisted throughout by Mr. George Anderson, was responsible for the construction of the Great Central Works at Bow Common, having previously had charge of the Surrey Consumers' Gasworks at Bermondsey, which last he worked upon a lease. These works are rather special; they show very great economy of material and design in the details of the larger constructions, and worked, into quite modern times, a combination of iron retorts with clay, utilizing on the more susceptible metal the waste heat from the higher temperature at which the clay retorts were operated in adjoining settings. This system accomplished in its day a very large economy of fuel. This gas undertaking was the pioneer of the supply of cheap gas in and around London, where it was founded to compete with the Chartered and the old City Companies. It was absorbed, together with the City Company, by the Gaslight and Coke Company, in pursuance of the new legislation of 1868, which will be dealt with later on.

Carrying on the development, and belonging to a later period than the foregoing, came:—

T. Newbigging, of Bacup, in 1864, some time in charge of important works at Pernambuco, and later Consulting Engineer in Manchester, the writer of several very useful Manuals and books of Tables for Gas Engineers. Specially he was Editor of "King's Treatise on Gas Lighting," an important work running into three quarto volumes, published from 1878 onwards. Mr. Newbigging had a very happy knack of writing on subjects outside gas altogether, of general or local interest, and showed considerable culture and poetic taste. His wide experience and attainments made him a very important figure in the history of gas and won for him an extensive consulting practice.

J. B. Paddon, for many years connected, as Engineer and ultimately as Chairman of the Directors, with the history of the

Brighton and Hove Gas, played an important part in its extension and was responsible for some extremely difficult work of an unusual and very interesting kind to the Civil Engineer. Particularly was this shown in the completeness of his designs and plans of all sorts of plant. He acquired a very special skill in recovering land from the sea, by the study of groyning, by which he gained a very large area for the site of the important gasworks at Portslade, near Hove, before the accomplishment of which he had some exciting experience in battling with the storm influences affecting the beach on which his works are constructed. His great success in this matter makes it unfortunate that records were not left, for the guidance of Engineers charged with maintenance, and security from coast erosion generally. He developed many other important undertakings: Southampton, Winchester, Lewes, Southgate, Lea Bridge, Hornsey, and was a Director of the Gaslight Company.

G. W. Stevenson.—No record of the persons engaged in the development of gas could be complete without reference to Mr. G. W. Stevenson, formerly of Halifax, who secured the erection of the gasworks at West Bromwich by competitive plans. This gentleman was mainly engaged in the last years of his life in arbitration and Parliamentary work.

Jabez Church, in the Eastern Counties, had a considerable practice in gasworks of a secondary scale.

Thomas Kirkham, of the Fulham Gasworks of the Imperial Company, carried out very large extensions of those works and also was responsible for the construction of the new Bromley Works of the same company, which is of large scale. He was responsible for no less than six gas-holders.

Robert Morton, the inventor of many useful devices in connexion with gasworks construction and administration, was for many years in charge of the London Gasworks, until its amalgamation with the Gaslight and Coke Company.

T. G. Barlow, formerly editor of the *Gaslight Journal*, was for some time engaged as Consulting Engineer to the Dublin Gas Company. Before that he carried out a number of works on the Continent, working with Messrs. Manby and Wilson, who with

him played a considerable part in the establishment of works at the important towns of Havre, Rouen, and Amiens, now the property of the European Gas Company.

Sir Corbet Woodall, first at Woolwich, later at the Phœnix Gasworks at Vauxhall, became Chief Engineer to that Company, following William Innes. He retired on the amalgamation of the Company with the South Metropolitan, and for many years carried on an extensive practice in arbitration and Parliamentary work, at the same time being associated with the direction of many important gas undertakings, of which the chief was the Gaslight and Coke Company of London, until he died early in 1916. He constructed specially a holder for 3 million cubic feet at Kennington, in which he dispensed with truss framing, having given his allegiance to that form of economic construction in early days.

Thomas Hawksley.—But for extent and magnitude of practice in gasworks construction, carried out from 1830 to 1893, Mr. Thomas Hawksley could not be equalled by any engineer of any date within the nineteenth century or since, and this is obvious from the list (given below) of the works he built for towns he originally supplied with gas—apart from the extensive consulting practice on works construction and Parliamentary and arbitration proceedings —and if it be remembered that his practice was chiefly in waterworks of extensive scale, in course of which he brought water into no less than 150 towns in England and abroad, it will be clearly seen that his work was simply prodigious in extent and variety. To illustrate this, I appeal to the list of gasworks designed either in whole or in part by Thomas Hawksley, and carried out under his direction :—

Great Britain: Nottingham, Sunderland, Derby, Cambridge, Oxford, Burton-on-Trent, Folkestone, Radcliffe, Chesterfield, Mansfield, Barnsley, Gosport, Bishop Auckland, Newark-on-Trent, King's Lynn, Normanton, Victoria Docks, Lowestoft.

Foreign Countries and Colonies: Melbourne (Australia), Bombay, Hobart (Tasmania), Launceston (Tasmania), Danish Gas (Copenhagen).

Seeing that Thomas Hawksley had, in the early days, little

assistance from contractors with experienced or skilled labour, foundries, rolling mills or machine-tools, and therefore had largely to teach his various contractors in all the specialities, such as retort setting, gas-holder and tank construction, as well as in purification plant and largely in steam plant, his labours must have been such as would have overpowered anyone with a weaker physique and less vital energy.

An examination of his earlier works, which were of Roman endurance, shows that the number of explosions which alarmed the public very much (such as those at Westminster in purifiers, in 1814, which injured Clegg, of the gas-holder at Manchester in 1819, the purifiers at Old Kent Road in 1835, the benzol explosion at the London Gasworks in 1857, which killed Michele) made it appear necessary to impart a strength of material that to-day is not found necessary. It, however, had the merit of an endurance which made the old plant valuable and serviceable when replaced to work in fresh situations.

Specimens of Mr. Hawksley's work, in designs and drawings for the Derby Gasworks, 1871–2, were shown. For fulness and completeness of detail and finish they would not be excelled, if equalled, in any Engineer's office at the present day. They are good standards in all respects.

Mr. Hawksley shone when advising Parliamentary Committees. He carried conviction by his thorough practical acquaintance with his subject and the prompt and fluent expression he could give, in legal terms, to frame any suggestion suddenly arising for alteration of clauses. This was cheerfully acknowledged by his many friends at the Bar. He was very sympathetic with the difficulties of young engineers and freely helped them with technical advice, and on occasions when necessary he had no difficulty in helping them in a more substantial fashion.

In the Institution of Civil Engineers, of which Mr. Hawksley was a President, and for many years a leading Member of the Council, his memory is deservedly preserved as an Engineer of the first eminence and distinction, and of unimpeachable personal honour. He was a Member of the Council of the Institution of

Mechanical Engineers from 1862, and was President for two years, 1876–77. He was the first President of the British Association of Gas Managers, presiding at the first General Meeting in 1864, when there were gathered round him most of those who have been referred to as occupying important positions in the progress of gas supply. His extraordinarily useful and successful career, extending over so long a period, makes him an exemplary figure for the followers of his Profession. He must certainly be considered an important pioneer in the history of Gas Engineers during the last century.

Sir George Livesey.—There is no other such striking personality in the history of Gas Engineering until we come to the late Sir George Livesey, very like Mr. Hawksley in the personal qualities of courage, originality, and resource in difficulties, strong in will and fixed in purpose, and, like him, kindly, helpful, and considerate to the point of gentleness where sympathy came in. Though not engaged so widely and variously, Livesey executed some of the largest and most original departures in gasworks constructions. These were illustrated by a lantern slide showing the Plan of the East Greenwich Works of the South Metropolitan Gas Company, which are equal to the large daily output of roughly 30 million cubic feet. There you have not only jetties, viaducts, wharf walling, deep tanks and the loftiest gas-holders yet ventured upon in this country, extensive carbonizing retort buildings and special purifying plant, but also a tar distillery, sulphuric acid works, and plant for following up all the ramifications and labyrinths of the enormous family of secondary by-products arising therefrom. Thus he executed works of serious Engineering difficulty, in connection with deep foundations, sand pumping and grabbing through water-bearing strata, mining, construction of deep tanks in unstable soils often water-logged and under heavy pressure from neighbourhood of main river channels.

Besides the execution of some of the largest and boldest constructions in gas plant and works containing novel principles, such as gas-holder tanks in concrete, holders without internal framing, and of late years omitting the upper sections of the

external framing, omitting houses of protection for such portions of the plant as purifiers and station meters, the introduction of generator furnace work for retorts fed centrally from external producers on lines very much the same as those of Mr. Foulis, of Glasgow; finally constructing gas-holders of enormous capacity (one of 12 millions per diem with six telescopic lifts), while generally advising freely and gratuitously a large number of his professional compeers in important works, Sir George played an unexampled part in swaying and directing the policy and financial aspect of gas supply over the eventful period between 1865 and his death in 1908. Only in less degree than the late J. O. Phillips, General Manager of the Gaslight Company, was he active in amalgamations, which he brought in all cases to a complete financial success, while he rapidly reduced the cost of gas to the consumer. He fought to a victory one of the most determined and protracted strikes, and thereafter established a new and most successful settlement of labour conditions by means of his profit-sharing system, later called the co-partnership. (His workmen-Directors scheme was only followed by the Crystal Palace Company.)

He may be credited with the present form of the sliding scale clauses, for adjusting the dividend inversely with the price of gas, which are now almost universal, though it is right to say that a scale, working only upward on dividend, had existed in one or two cases before. In advising this method, he did not hesitate to criticize very severely the machinery enacted in 1868 for revising the terms of price of gas by a court of referees. Perhaps his services to the industry were most important in removing the vexatious and useless restrictions on the manufacture of the gas, and still more in securing that the means of testing employed fair and suitable methods and standards.

His position as Chairman of the second most important Gas Undertaking in the world, with control of ample resources for supporting the burdens of successive Parliamentary battles with the Authorities who were vested with the control of the testing, enabled him to prosecute his aims and measures always to a successful end, based as they invariably were on the policy of

protecting the real interests of the consumers. By courageous and successful appeals to Parliament, he liberated the industry from the trammels and the crippling ties of being legislatively submitted to tests of a vexatious and a necessarily microscopic character. These comprehended heavy penalties for infinitesimal proportions of ammonia not removed from the gas, though the value of such ammonia, when recovered, was at least £50 a ton, giving every possible impulse to its being abstracted. A form of impurity present in very small proportions, namely, bisulphide of carbon, was visited with very heavy penalties for a few grains per hundred cubic feet. With the modern class of burners, which reduce the consumption per unit of light thirty-fold, the injury, always very doubtful, was proved, to the satisfaction of a Commission, to be negligible.

Again, he relieved the industry from the use in testing for illuminating power of a burner which exaggerated small deficiencies, as it was incapable of testing with accuracy, and without serious damage to the gas, for small defects. The correction of this injustice has enabled a calorific standard to be fixed which is satisfactory alike to both the consumer and the supplier, and is, moreover, a very much simpler method of determination of the value, being much less liable to personal variation, defective sight, etc. The inventor of the burner, the adoption of which brought about this condition, was Dr. Charles C. Carpenter, *Member*, Chairman of the South Metropolitan Gas Company.

The source of Livesey's extraordinary influence was his obvious sincerity and earnest purpose. His great breadth of grasp and thorough knowledge of the subjects he studied and made his own, made him the most convincing witness, and no cross-examination could shake him, as his views were very firmly and deliberately formed, and from all sides of the question. Those who differed from some of his views could never regard him without entire respect. After overcoming a dangerous strike, which lasted for many weeks, by his masterful and able methods of providing for the workers, he devoted his mind to a very careful study of the labour problem. This led him to the establishment of equitable and co-operative

systems, the successful development of which at, successively, the South Metropolitan, the South Suburban, the Commercial, and many other companies, made him much regarded in public opinion as an authority on social questions.

Through many years he exercised so benignant an influence over the district in which his chief work of the South Metropolitan Gas Company lay, that his funeral furnished the extraordinary and impressive sight of some two to three miles of streets lined two-deep with men, women and children, quite outside a large number of employees who were present at the cemetery.

Having dealt with the personal elements at work I would now deal finally with the general position of the industry to-day and the problems still before the Gas Engineer.

A development of special consequence in the later years arises from the Slot Meter consumption, which is found to be very valuable as levelling the load between summer and winter. This enables capital already spent to be more fully utilized in works and mains and services, while the nature of the demand so far dispenses with the need for storage that large capital outlays contemplated in the past have proved for the present to be unnecessary. In this way the slot consumer may claim to have been specially profitable, and therefore to be entitled to consideration in the price. A very similar claim has arisen and been met by discounts on daylight and summer consumption in factories which are rapidly realizing the value of gas-power in engines, and even still more the efficiency of gas in heating, smelting, and countless trade operations. A measure is afforded of the advantage arising from this development between 1900 and 1915, in the progress of three of the lowest-priced gas companies in and about London. From 1900, on a joint mileage of 1,403, there was an increase up to 1915 of 540 miles = 38 per cent., while consumers per mile increased from 262,020 to 566,859 = 113 per cent.

A further proof is given by the experience of the Wandsworth, Wimbledon, and Epsom District Gas Company, 40,000 slot-meters consume in the summer six months 10,207 cubic feet each, against

the consumption in the winter six months of 11,026 cubic feet each, or within 8 per cent. of the same quantity in summer as in winter. As in the case of many other undertakings, the highest peak of the demand is between midday and 1 p.m. on a summer Sunday. It is clear this increasing domestic use must displace coal, and to that extent counteract the rise in coal prices. It is interesting to learn that His Majesty's Mint and Messrs. Rothschild's Refineries consume respectively as much gas as towns of 10,000 inhabitants, as both find the power of gas, applied in suitable furnaces, to be greater than that of any fuel of equal cost. In this relation, one London Gas Company which has been making munitions, and to that end melting down and amalgamating certain important metals for fuses, has been asked to extend their work in smelting on the ground that the metals so reduced are found to give higher tests of value than those prepared generally elsewhere. This preference must be specially gratifying, as it points to the extension of service in a new and unsuspected direction.

Generally, it must be recognized that as the incandescent light of Welsbach only needs an adequate heating-power, the old aim at illuminating-power, *per se* (in the early years the only object of gas manufacture), has now finally given way to the far more generally useful heating-power. If this be so, our former anxious efforts, at great sacrifice of cost, are no longer needed, and what we have to do is to find a really cheap, serviceable fuel, to be distributed by our systems of arterial and service mains, such as will meet all wants. Our distributing systems would not deal with a very low grade heating-gas, even if such a gas would be generally useful, which is more than doubtful; but we must recognize the demand will necessarily be for the cheapest fuel of like efficiency.

It is impossible to maintain the old traditions and prejudices, and it is therefore a very welcome opening that is being given by the Government in the shape of Mr. Pretyman's Act of Parliament, enabling specially such undertakings as are recovering hydrocarbons for War Services to exchange their present illuminating-power standards for a heating standard. The special experience of the Wandsworth, the South Suburban, and the Gaslight Companies,

who accepted this change some years ago, has been that it gives no practical inconvenience or loss to the consumer, while it affords considerable latitude towards economy of production to the gas-maker. As nearly all the gas companies are under Sliding Scale Legislation it follows that from three-fourths to nine-tenths of any saving arising will react in reducing the selling-price of the gas, and that again will operate to the expansion of the supply.

War Demands.—This leads to the consideration of what aid is being given directly to War Service in entirely new directions. While undergoing a restricted supply of coals and shipping which largely increases our costs, and a denuding of our manual labour to the point of exhaustion, the larger gasworks, already making shells and fuses, have been further called upon to recover certain hydro-carbons and to furnish ammonia in concentrated form, as well as certain acids, and this demand has been met to such an extent, that some large works where special efforts are being made are almost devoted to War Service. This is all being done without profit of any kind, and even the services of head of staffs are further given ungrudgingly, as indeed should be expected in a national emergency. One must believe that the experience gained in doing these things in war time will react and enure to future benefit when peace is restored.

Under war conditions, as the Ministry of Munitions stated to the Westminster City Council, no profit can arise to the Gas Undertakings, who indeed have been put to considerable out-of-pocket expenditure in order to secure the operations in addition to the permanent cost of working. After the war is over, there is reasonable hope that the various plants installed for National Service may continue to be employed in productions useful in the Arts and Manufactures of the country at large. This would assist in reducing the price of gas to the consumer, as it adds value to most of the residuals.

It is obvious that all economies realizable in this way are, in the interests of gas consumers, best got at the source of the supply. They arise from bulky and somewhat unsavoury raw products, so that the cost of transport and re-transport of products should be

saved and the control kept in the hands of the producers. Even the sulphur, which is the chief impurity in crude gas, is now easily recovered from the spent purifying material and turned into sulphuric acid, which again fixes the volatile ammonia in the condensed, convenient, and valuable form of the sulphate, for which there is a world-wide demand as fertilizer.

In pursuance of these valuable productions, and the consequent profit to the user of gas, the companies have, with Government aid, extended and developed their plants for war purposes, but there can be no doubt whatever that all these products will have a permanent value in the future, and that the importance of them all will be widely recognized. Our astute enemy, Germany, has for years past been acquiring and accumulating our products, which gave great advantage for the first months of fighting.

Problems.—The Engineers of to-day: What task is before them? What problem is to be solved? Is it not to find a gaseous fuel, superior to the producer-gas, and therefore worth distributing, and yet cheaper than that which is now supplied, because the valuable residuals should all be recovered to the last ounce? Are we not working towards it by the successive steps of discarding cannel and high-power gas in favour of a universal standard of an adequate calorific efficiency, but calling for no fanciful cost or waste in its preparation? The specific gravity of such a gas enables it to be distributed at a low cost, whether of capital in canalization or for the propulsion. Dr. Mond shows us that for gas of low calorific values the recovery of ammonia is so increased as to greatly diminish the net cost for material; and we may have much to learn here. But the larger volume necessary to carry the same thermal efficiency puts so weak a gas out of the range of suitability for town distribution through the systems of main pipes as existing.

These systems represent a large expenditure, and are so packed below costly pavements as to prohibit their replacement or enlargement except by hazarding a great capital outlay. If they are to be used and made most serviceable, even under greater compressions and propulsion costs, clearly we must not lower much further the present standard of calorific. Has not the replacement

of tests for illuminating power by calorific test already rid us of the fanciful and expensive expedients that formerly were demanded by the damaging effects of unsuitable testing burners of destructive action? Can we not establish the real fuel value of our coke—improve the output of ammonia—seek out and bring to account all the value of the numerous family of hydrocarbons that is resident in the tar, such as fill so many practical uses in arts, colours, scents, antiseptics, drugs, solvents, motor-power fluids, road-making materials, fertilizers, acids, and the countless other products, and so realize a cost of production under improved labour-saving appliances so as to enable us to supply power and heat for all purposes, trade and domestic, at charges which would make it worth no one's while to employ any other sort of fuel, specially looking to the facility of obtaining it unlimited at will afforded by the constant supply from the street mains.

For rural communities, scattered over areas remote from railway depots for coal, the supply of heat by gas carried at a nominal cost in the arterial mains is a great boon, because the cartage of coal on such small scales and over such distances as they require is practically prohibitive. Gas can quite profitably be distributed on so low a demand as $1\frac{1}{2}$ million cubic feet per mile without incurring a cost for capital and working charges of more than 2*d.* to 3*d.* per 1,000 cubic feet.

It is a source of satisfaction to remember that the use of town gas in the earliest and crudest forms of internal-combustion engines (which the industry has always helped and encouraged by adoption and employment long before they reached their present efficiency and economy) has developed to a general service which seems much appreciated by power-users at large. The employment of ordinary town gas for this purpose grows continuously, and is especially in favour on the Continent, where gas companies are under the greatest pressure to hire and sell the engines to power-users of all scales.

It is clear that the perfecting of the gas-engine, in which Dr. Dugald Clerk has played a very prominent part, has led to and made possible the auto-motor cars and traction engines as well as

for the purpose of aviation. Mr. Hanbury Thomas lately stated that the Sheffield Gas Company had in the last five years raised the number of gas-engines supplied by 15,116 h.p., and that the total quantity of gas so supplied in 1915 was 789 million cubic feet annually. This figure may be better understood as demanding the use of about 72,000 tons of coal. The development of the growing use of gas, in replacing smelting and other furnaces demanding the highest heats, by the Sheffield Company, is equally shown by the fact that the Company have sent out 642 furnaces, using 372 million cubic feet of gas.

Professor Bone is responsible for the statement that 60 millions sterling yearly could be saved, by the replacement of gaseous fuel for the raw coal, by the values saved of the by-products on the former system. Obviously the national interest demands that the direct use of raw coal for heating purposes, where a solid fuel is not indispensable, should be controlled and checked so that all the valuable elements should be recovered. For such uses as a solid fuel would appear desirable, the residual coke can be proved to be serviceable, with the advantage that it is smokeless, sootless, and more enduring, weight for weight, than coal, while it yields less impurity to contaminate any substance or metal heated by it.

The Board of Trade Return of Total Annual Coal Production is put at 189 million tons in 1913. Of this, 16 million tons is used by gasworks, which also might use 2 million more by avoiding the use of imported oil: say, a total of 18 million tons—in the whole of which the by-products are recoverable. The coke ovens account for 20 million more, according to Professor Bone, of which only some two-thirds have the by-products recovered; making, therefore, a total of 32 million tons, or little over one-sixth of the whole, which is economically used, and after allowing for export it is clear that there is an enormous national loss going on.

One must support the further view of Professor Bone, that the practical chemist has an extensive and important future in guarding against this loss and in helping to its avoidance. From having personally enjoyed the assistance in gas management from so early a date as 1875 of distinguished chemists, I can endorse the

Professor's urgent advocacy for the fuller and wider employment of chemical science. But I must insist that it shall be supplementary, and not to replace the engineer's science, always demanded, and of which I have quoted notable and successful examples.

The claims of the War have conferred a new sphere of usefulness upon us, which, as it serves the national safety, adds nothing short of a special dignity to our work. Let us see that we spare no personal effort in this hour of trial to give the best that is in us, and above all, let it rouse our sense of responsibility to do honour and give credit to our profession by persevering study and faithful loyalty to the worthy examples afforded by our predecessors, "The Gas Engineers of the Last Century."

The Lecture is illustrated by Plate 5 and 3 Figs. in the letterpress.

The attendance was 52 Members and 53 Visitors.

The LECTURE was repeated by Mr. JONES in Cardiff, at the South Wales Institute of Engineers, Park Place, on Thursday, 9th November. Mr. DAVID E. ROBERTS (*Member*) presided, and 30 were present. Mr. JONES, in replying to a Vote of Thanks, reminded the Meeting that, in addition to works referred to in the Lecture, Thomas Hawksley had carried out some extensive waterworks in South Wales, and had installed over 150 waterworks of the highest importance in the United Kingdom.

The Institution of Mechanical Engineers.

PROCEEDINGS.

November 1916.

An Ordinary General Meeting was held at The Institution of Civil Engineers, London, on Friday, 17th November, 1916, at Six o'clock p.m.; Dr. W. Cawthorne Unwin, F.R.S., *President*, in the Chair.

The Minutes of the previous Meeting were read and confirmed.

The following Paper was read and discussed :—

"Report of the Hardness Tests Research Committee."

The Meeting terminated shortly after Seven o'clock. The attendance was 45 Members and 38 Visitors.

REPORT OF THE HARDNESS TESTS RESEARCH COMMITTEE.

The Committee was appointed in 1914 "to report on a Hardness Test for Hardened Journals and Pins," and its membership now stands as follows:—

W. Cawthorne Unwin, LL.D., F.R.S., *Chairman;* Archibald Barr, LL.D., D.Sc.; Sir Robert A. Hadfield, D.Sc., D.Met., F.R.S.; Captain H. Riall Sankey, C.B., R.E., ret.; T. E. Stanton, D.Sc., F.R.S.; and A. E. H. Tutton, D.Sc., F.R.S.

The Committee originated in some letters from the Mirrlees Watson Company to the late Mr. Leslie Robertson, the Secretary of the Engineering Standards Committee, who suggested that the question was one suitable for investigation by a Research Committee of the Institution. The Mirrlees Watson Company wrote that "they had found difficulty in fixing a standard of hardness—for instance, in bearings where shafts or pins work at high speeds under heavy loads."

The Committee has held several meetings, and has corresponded with some manufacturers and others who were likely to have adopted some method of testing hardness.

A memorandum was prepared by the Chairman, Appendix I (page 701), on such methods of testing hardness as were known to have been used. It appeared that for ductile materials an indentation test (Brinell or Shore scleroscope) was largely used, and was found to give useful information. Both these methods

appeared less satisfactory for very hard materials, such as those indicated in the reference to the Committee. Further, it had been shown by Mr. Saniter that resistance to wear, as in the case of a pin or journal, did not directly depend on the hardness as measured by the indentation test.

The question of the property of materials which ensures resistance to wear on rolling or sliding surfaces appeared to be strictly within the reference to the Committee. It was therefore decided that experiments on resistance to wear, and especially in the case of dry surfaces, should be made at the National Physical Laboratory. Dr. Stanton designed more than one form of testing-machine for this purpose, and carried out the researches of which an account is given in the Paper which forms part of this Report. Brinell and scleroscope tests were made at the same time, so that a comparison could be made between the resistance to wear and the ordinary indentation measure of hardness. The form of testing-machine designed by Dr. Stanton, in which there is a definite sliding between dry revolving surfaces, seems likely to be of considerable value in solving the precise question put forward by the Mirrlees Watson Company.

The Committee is much indebted to Sir Robert Hadfield for supplying the materials on which Dr. Stanton's tests were made; also to Mr. R. G. Batson, of the National Physical Laboratory, to whose care in making the tests the success of the research was due. The Research Council of the Board of Education have made a grant of £100 supplementing that from the Institution.

Report on Experiments made at the National Physical Laboratory by Dr. T. E. Stanton and Mr. R. G. Batson.

A description of the nature of some of the better known of the various tests which have been devised for obtaining the relative resistance of materials to surface deformation, to all of which the term "hardness tests" is sometimes loosely applied, is given in Appendix I (page 701) by the Chairman of the Committee. A preliminary examination of these methods shows that each of them falls into one or the other of two distinct categories. These are:—

(1) Abrasion or scratch tests, in which particles of the material whose "hardness" is to be determined are torn away from its surface by sliding contact with some other substance, whose corresponding resistance is so high that its surface remains unimpaired by the action.

(2) Indentation tests, in which the surface of the material under test is permanently distorted by the pressure of a hard steel ball, cone, or knife edge.

If each of these methods were a measure of the same definite property of the material which is as characteristic of it as, say, its elasticity, it is evident that the ratio of the results of any two of the methods would be the same for every material tested. Comparisons between the results of these various tests have formed the subject of several researches which have been published during recent years. The general conclusions, as summarized by Professor Turner in his Paper on "Hardness," read at the Iron and Steel Institute Meeting of 1909, appear to be that, although an approximate agreement may seem to exist between the various methods when applied to the case of relatively pure metals in their cast or normal state, yet when the resistance to deformation is due to tempering or to mechanical treatment no comparison is possible.

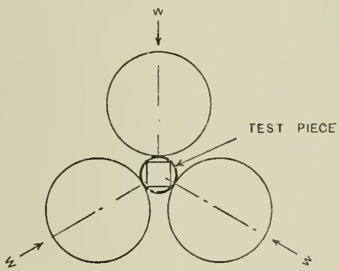
That this should be so would seem to follow from the consideration that the resistance which any so-called hardness test is supposed to measure is that which the body under test exerts against a complex distribution of stress over its surface which has partially deformed or disintegrated it, and it is evident that its value will depend, not on the stress constants of the material such as its yield-point, ultimate tensile and shear stresses, but on intermediate stresses, the precise nature and distribution of which are unknown and whose ratio to the stress constants may not be constant for the same method. If, therefore, such resistance, without qualification, be defined as the hardness of the material in its broadest sense, it is clear that, as pointed out in the memorandum to the Committee communicated from the members of Sir Robert Hadfield's laboratory (Appendix II, page 707), hardness is no more a definite quality of a material than is the strength of a piece of

steel of definite dimensions. In the latter case, if the nature, amount and distribution of the stress are known, its resistance has a definite value which can be calculated. The only difference between this case and that of the hardness test is that, since in the determination of hardness there is no possibility of estimating the stress magnitude and distribution, we are driven more to direct observation of the consequences of such distribution than to a calculation of these consequences from the known characteristics of the material. Mechanical phenomena of this kind are familiar to engineers under other aspects, such as in the cases of the resistance of ships and aircraft to propulsion; but whereas in these latter cases the problem is to determine the resultant force exerted by the unknown pressure distribution, in the present case, as in the corresponding one of the resistance of materials to impact, the unknown quantity is the ultimate resistance of the material to the unknown stress distribution. In all the cases, however, the practical method of solution is an experimental one, and consists of setting up a similar, or nearly similar, state of stress on a specimen of the material whose behaviour is under investigation and noting its effects.

It cannot, however, be said that modern engineering practice is entirely in accordance with the views laid down above, although the development of what are called "wear" tests in recent years is an indication that it is coming to be recognized that the results obtained in the relatively simple cases of stress distribution in the indentation test or the scratch test are not applicable to those in which the action is a combination of the two effects of normal pressure and sliding. For example, there are wear tests for measuring the particular form of disintegration which takes place on the surface of steel rails due to the rolling abrasion of heavily loaded wheels. The characteristics of this kind of wear are the extremely small amount of the relative movement between rail and wheel and the high intensity of the compressive stress at the line of contact. On the other hand, there are wear tests of lubricated surfaces in which the pressure is relatively small and the rate of slipping large.

Notwithstanding this development, there seems to be no doubt that with many engineers it is still customary to regard the hardness as determined by an indentation test as a definite property of material, and as a measure of the resistance of the material to wear of any possible kind that is likely to be experienced in its use. In the face of this practice it appears to be of importance to determine under what circumstances the custom here referred to may be flagrantly misleading, or merely a rough guide which is better than no guide at all. As pointed out in Sir Robert Hadfield's memorandum, the use of an indentation test in the case of manganese steel rails is highly misleading; but, on the other

Fig. 1.—*Method of Wear Test by rolling Abrasion.*

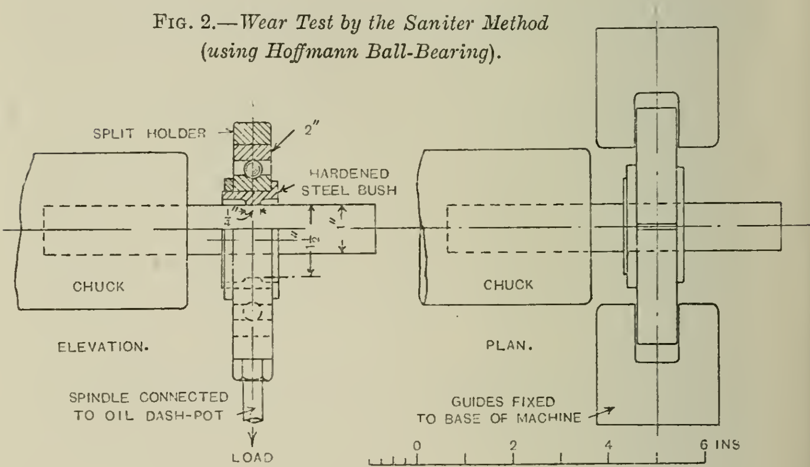


hand, in Mr. Saniter's wear tests of ordinary carbon steels the correspondence between the results of the indentation and wear tests was fairly close.

On looking into the available evidence it appeared that the ground hitherto covered was not sufficient to enable any broad generalization to be attempted, and the Committee therefore decided, as a preliminary research, that a comparison should be made of the results of both hardness tests and wear tests of materials whose composition and thermal and mechanical conditions of production extended over a wide range. A series of experiments for this purpose were accordingly undertaken at the National Physical Laboratory.

On consideration of the method of wear test to be adopted, the use of the machine previously constructed in the laboratory for wear tests under rolling abrasion suggested itself. In this machine the specimen is in the form of a disk 1 inch diameter and about $\frac{1}{4}$ inch thick, which is placed between three hardened steel rollers as indicated in the sketch, Fig. 1, each roller being capable of independent rotation in a practically frictionless bearing. The upper roller is loaded with a weight, W, and its axis is also free to move in the vertical direction, so that when it is rotated motion is

Fig. 2.—*Wear Test by the Saniter Method* (*using Hoffmann Ball-Bearing*).



communicated to the lower ones by the rolling friction of the ring. By making the ring solid and the load considerable, the machine is used for wear tests under rolling abrasion, or by making the ring hollow and using comparatively small values of W the test becomes a fatigue test under alternating bending stresses.* Several preliminary sets of tests were made in this machine, and the results were considered fairly satisfactory; but it was felt that the machine could not be recommended for general workshop use owing to the complication of working parts and the extreme care needed to

* Journal, Iron and Steel Institute, 1908, No. 1, pp. 54-70.

prevent slipping of the steel rollers as the test proceeded and the specimen became worn. It was decided, therefore, to make use of some simpler form of rolling abrasion test, and as a Wöhler fatigue testing-machine was available which with slight alterations could be adapted for wear tests by the method used by Mr. Saniter,* the necessary modifications were put in hand.

In this method the specimen is fixed in a chuck revolving at a high speed and carries a hardened steel ring (of internal diameter about twice that of the specimen), to which is attached a dead load and wear takes place due to the rolling of the steel ring on the surface of the specimen, Fig. 2. In Mr. Saniter's machine the diameter of the specimen was $\frac{1}{2}$ inch, the internal diameter of the wearing ring was 1 inch, the speed was 4,000 revolutions per minute, and the load 205 lb. In the fatigue testing-machine adapted for the present tests, the speed was 2,200 revolutions per minute, the diameter of the specimen was 1 inch, and that of the ring $1\frac{1}{2}$ inches. The load was 410 lb.

The wear was taken as the reduction in diameter in ten-thousandths of an inch after 200,000 revolutions of the specimen.

As it was considered desirable to have a quantity to represent the resistance to wear, this was taken to be the reciprocal of the above values multiplied by 1,000.

The materials used for the tests consisted of six differently heat-treated specimens of nickel-chromium steel containing 0·7 per cent. carbon and two samples of manganese steel, kindly supplied by Sir Robert Hadfield. On analysis the composition of these steels was found to be:—

	C.	Si.	Mn.	Cr.	Ni.
Hardened Steel . . .	0·7	—	—	2·0	2·5
Manganese Steel . .	1·36	0·36	13·10	—	—

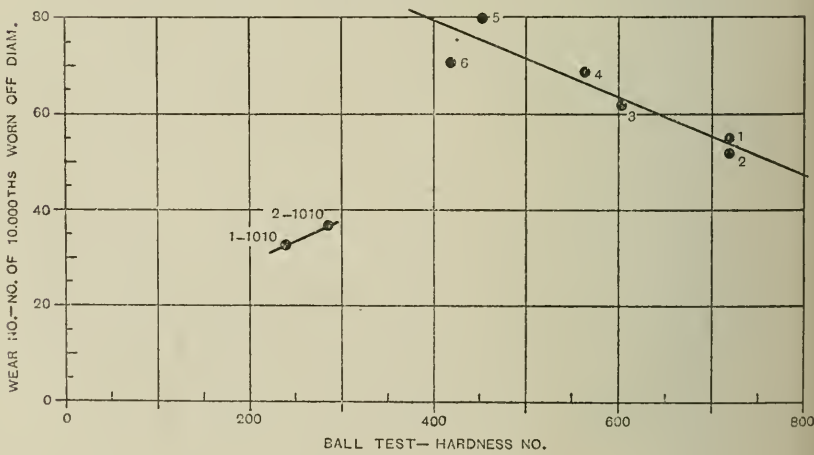
The results of the rolling abrasion tests on these specimens are given in Table 1, in which are also tabulated the particulars of the heat treatment, supplied by Sir Robert Hadfield, together with Brinell hardness tests and scleroscope tests of the surfaces before and after wear, made at the National Physical Laboratory.

* Journal, Iron and Steel Institute, 1908, No. 3, pp. 73–80.

TABLE 1.

Marks.		Hardening.	Tempering.	How Tempered.	Brinell Hardness No.		Scleroscope No.		Wear.	Resistance to Wear.
One end.	Other end.	Temp.	Temp.		Unworn Surface.	Worn Surface.	Unworn Surface.	Worn Surface.		
8986–1	1	850° C. Oil	None	—	720	—	98	108	55	18
,,	2	,,	200° C. Air	Oil Bath	720	—	98	113	52	19
,,	3	,,	300° C. ,,	,,	605	605	90	101	62	16
,,	4	,,	400° C. ,,	Melt.	565	565	86	90	69	14·5
,,	5	,,	500° C. ,,	Gas Muffle	453	455	77	80	80	12·5
,,	6	,,	600° C. ,,	,,	420	420	67	71	71	14
1 M	(Manganese Steel)		950° C. Water	—	219	230	34	71	33	30
2 M	(Manganese Steel)		as forged	—	277	284	44	78	37	27

FIG. 3.—*Wear Test on Sir Robert Hadfield's Specimens, by the Saniter Method.*



For convenience of comparison, the results of the rolling abrasion tests and the ball hardness tests on the original surfaces are also plotted in Fig. 3, in which the ordinates are the values of the wear as defined above and the abscissæ the corresponding values of the ball hardness test, determined in the following manner:—

The ball, 10 mm. diameter, and the specimen under test were placed between the compression-plates of a Wicksteed testing-machine, and the load run on to 3,000 kilos. (W), and allowed to remain at this value for 30 seconds.

The diameter of the indentation was then measured in a micrometer microscope, and the area of the indentation was calculated from the formulæ:—

$$A = 2\pi\left(R^2 - \sqrt{R^4 - r^2 R^2}\right),$$

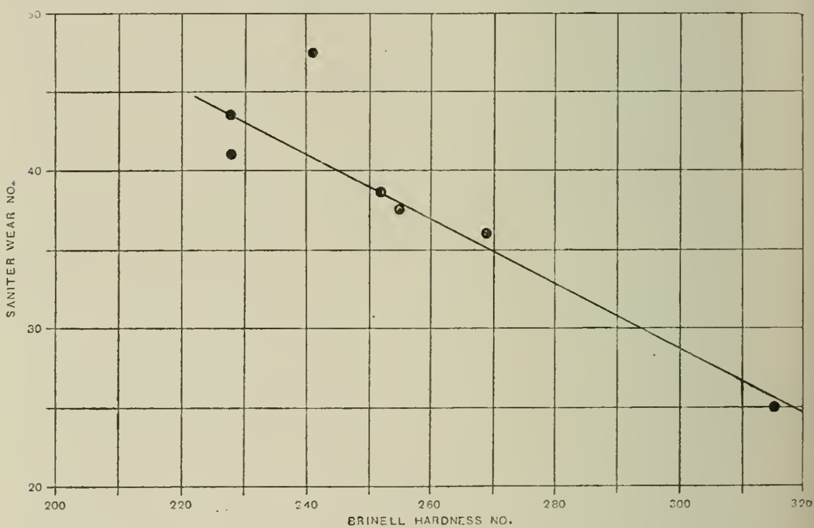
where R = radius of ball in mm. and r = mean radius of indentation in mm.

The hardness number was then taken as the value of $\frac{W}{A}$.

From inspection of Fig. 3 (page 684) it will be seen that the plotted points for the hardened steels lie fairly well about the straight line shown, and the results may be taken as an indication that for the same material the resistance to rolling abrasion is roughly proportional to the ball hardness number. This is in agreement with Mr. Saniter's experience with the same method of test as shown in Fig. 4 (page 686), in which his results for a 0·7 per cent. carbon steel heat treated in various ways are plotted. The comparison, however, is not a safe one, as cases frequently occur in which a considerable departure is found from this approximate relation. The extremely high value of the ratio of the rolling abrasion resistance to ball hardness number in the case of the manganese steels confirms existing knowledge of the properties of these steels, and is also in agreement with the results of Mr. Saniter's tests. As illustrating the important fact brought out in Sir Robert Hadfield's Memorandum that the resistance to rolling abrasion of manganese steels is the resistance to deformation of already deformed manganese steel, which is known to be high, it

will be seen from the values of the scleroscope hardness after rolling, given in Table 1, that in the case of the manganese steels this was practically doubled by the rolling, whereas that of the hardened steels was only increased by amounts ranging from 4 to 15 per cent. It is of interest to note from the figures that, even when this increase of hardness is allowed for, the resistance to

FIG. 4.—*Comparison of Saniter Wear No. and Brinell Hardness No. on a* 0·7 *per cent. Carbon Steel* (*Heat treated*).



rolling abrasion of the manganese steels is still considerably higher than would have been predicted from the ball hardness tests.

As regards the nature of the test, it may be assumed that, on first putting on the load, the yield-point of the material of the specimen on an extremely narrow strip of the surface of contact is exceeded, and that slight deformation takes place depending on the radius of the wear ring and the amount of the load. After a few revolutions, therefore, there will be a thin ring of material round the specimen which has been permanently strained, and whose resistance to deformation is greater than that of the original material. Wear will then begin to take place by the gradual

disintegration of this ring under the repealed loadings, and also under the extremely small but definite elastic slipping of the surfaces over each other, which is the well-known characteristic of rolling.

Another characteristic of the test is that part of the material worn away during the progress of the test appeared to be rolled into the surface again, and finally came away in flakes. In the description of Mr. Saniter's machine * it is stated that the speed of the machine is such that the abraded particles are removed by an induced current of air. This effect may be an advantage or otherwise, according to the similarity obtained to the conditions of practice. If the comparison required is the relative wear of steel rails, it would appear that the re-rolling action is a more exact copy of practical conditions of use than when it is prevented. It will be clear, however, that in this test what is actually measured is the resistance to disintegration of already deformed material, and that, as pointed out in Sir Robert Hadfield's memorandum (Appendix II, page 707), this resistance will depend on the amount of the deformation produced, and has little relation to the material in its unstrained condition. As regards the value of the method, it was considered that as a means of predicting the relative resistance to wear under conditions of rolling abrasion under heavy loads, that is, such as the wear of steel rails, the test was a comparatively easy and rapid method of obtaining the information desired, if the following precautions were observed :—

(1) The fixing of the specimen so that its axis is accurately in line with the axis of rotation of the chuck.

(2) Frequent renewal of the wearing ring, and calibration of each new ring on a specimen of standard material.

The reason for these precautions is that any slight vibration of the specimen increases the rate of wear, and this vibration may be set up by want of alignment of the specimen or by unequal wear of the wearing ring.

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* Journal, Iron and Steel Institute, 1908, No. 3, p. 75.

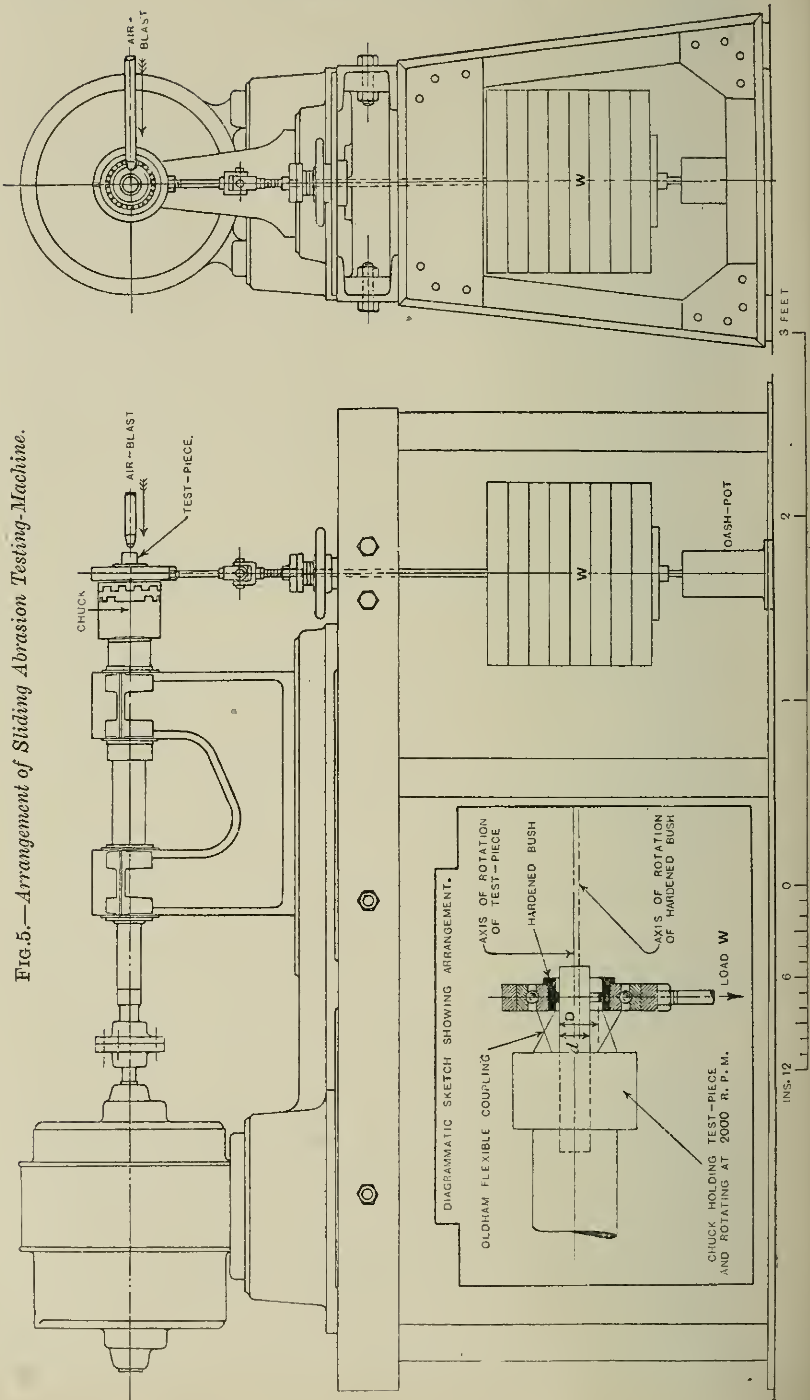
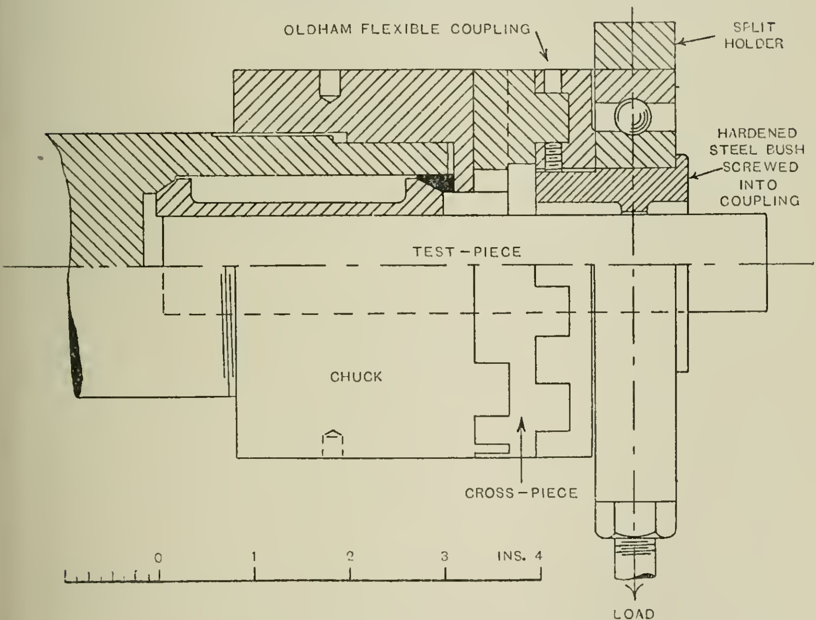


FIG. 5.—*Arrangement of Sliding Abrasion Testing-Machine.*

From the foregoing discussion of the characteristics of the rolling abrasion test, there appeared to be some probability that, although its results were applicable to cases of wear due to high pressure and very small relative motion, they might not be applicable to cases of the wear of surfaces in which the pressure is relatively small and the amount of relative movement is large. This appears from the consideration that in the latter case no

Fig. 6.—*Detail showing Specimen, Application of Load, Flexible Coupling and Chuck.*



permanent deformation corresponding to the yield-point is reached over the surface exposed to wear, but that by the relative sliding small particles are bodily detached without permanently distorting the surrounding particles. This is the case of the wear of workshop gauges, hardened steel pins and collars, etc. It was decided, therefore, as the next step to attempt to devise some form of wear test which would apply to cases in which the relative movement of the surfaces was considerable. A system of toothed

gearing connecting the abrading ring and the specimen first suggested itself, but on going into the design the mechanical arrangements were so complicated and costly that the machine was not put in hand. Finally, the idea occurred of connecting the abrading ring (internal diameter D) to the chuck by means of an Oldham coupling, so that both ring and specimen (diameter d) should complete a revolution in the same time, the line of contact remaining fixed relative to the machine. In this way πD inches of the surface of the ring and πd inches of the surface of the specimen passed the line of contact per revolution, the slip of the ring over the specimen would be $\pi (D - d)$ inches per revolution. The chief practical difficulty of the device appeared to be the difficulty of lubricating the sliding surface of the Oldham coupling so that it would run satisfactorily at 2,200 revolutions per minute, and it was evident that if the amount of sliding was large, that is, D considerably greater than d, there was a strong probability that seizing would occur. The chances of successful working appeared sufficient, therefore, to justify a trial of the method, and a design was got out. The details of the machine are shown in Figs. 5 and 6. The cross-piece of the coupling was made of brass with four slots on each side to make the wearing surface fairly large. On the completion of the machine some preliminary tests were made with different rates of slip, and it was found that with a load of 410 lb. the sliding surface of the coupling worked satisfactorily up to a slip of a quarter of an inch per revolution of the specimen, but that beyond this value there was a tendency to seize. The tests were accordingly carried out at this value of the slip. The results were quite satisfactory, but it was evident that if the tests were to be comparable with the wear of tools, gauges, pins, etc., it would be necessary to prevent the action referred to when discussing the previous tests, by which some of the abraded particles were continually re-rolled into the surface. This was accordingly done by directing a strong air-blast from a compressor on to the surface of the specimen during the whole of the test. By this means the abraded particles were removed, and any rise of temperature in the specimen was prevented.

The results of the tests by this method, which may be called a sliding abrasion test, were, in one important particular, in marked contrast to those obtained by the rolling abrasion method, in that they indicated a possibility of making a wear test without gradually impairing the condition of the worn surfaces. For example, taking an extreme case, even when the loads on the wearing rings were the same in the two methods, there was very little evidence in the sliding abrasion test of that gradual hardening of the surface as the test proceeded, which was so characteristic of some materials under the rolling abrasion test. This was shown by making tests with the scleroscope on the surfaces before and after abrasion.

As might have been anticipated, an important condition affecting the rate of wear was the freedom of the surfaces from the slightest trace of lubricant. In the early stages of the work it was found that occasionally a little oil was carried over from the air-compressor by the compressed air, with the result that the test was a complete failure, and it was not until special precautions had been taken to keep the surfaces dry that consistent results were obtained. Under these conditions, however, repetitions of the tests on the same specimen were in very good agreement.

It was considered, therefore, that for the object of the present investigation, that is, the comparison of the results of the ordinary ball hardness tests with those of a wear test of a satisfactory character, the machine here described would be quite suitable, and a series of tests on a wide range of materials was carried out. A large number of these materials was kindly provided by Sir Robert Hadfield, who also undertook the hardening of the special wearing ring used for the tests. In addition, tests were also made on some samples of steel used for the manufacture of gauges and other materials available at the National Physical Laboratory for the purpose of the work.

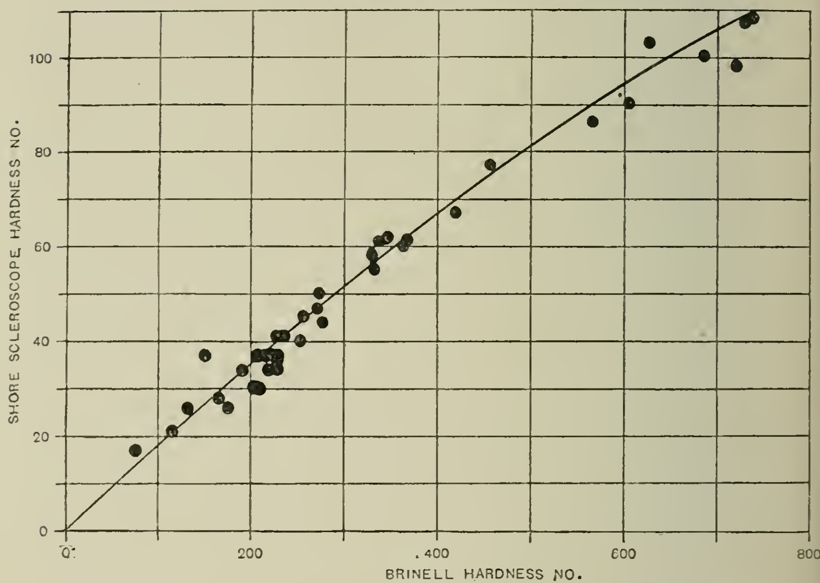
The determinations made on these samples were as follows:—

(1) The Brinell hardness number for the unworn surface (calculated as described above).

(2) The Brinell hardness number for the worn surface.

(3) The scleroscope number for the unworn surface.
(4) The scleroscope number for the worn surface.
(5) The wear expressed as thickness of surface layer worn away in mils. per 1,000 feet of slip.
(6) The relative resistance to sliding abrasion or the reciprocal of the quantities in column 5.
(7) Ratio of Brinell hardness number to scleroscope number.

Fig. 7.—*Comparison of Brinell Hardness No. and Scleroscope No.*



(8) Ratio of Brinell hardness number to resistance to sliding abrasion.

The values are tabulated in the order stated in Table 2 (pages 694–7).

The load on the wear ring at which these tests were carried out was the same as in the previous tests with the rolling abrasion tests, namely, 410 lb.

The reason for using a high value of the load in the sliding abrasion tests was that, although a satisfactory rate of abrasion

could be obtained with loads as low as 100 lb., the wear of the specimen was much more uniform when the higher pressure was used. At the low pressures there was a tendency for the specimen to become elliptical, so that the determination of the wear was difficult. The adoption of the high value, on the other hand, undoubtedly caused the relatively small hardening up of the surface of the specimen which was detected in a few instances under sliding abrasion.

General Results of the Tests.

(1) *Ratio of Brinell Hardness Number to Scleroscope Number.*

The results of these determinations have been plotted in Fig. 7, and are in approximate agreement with the general assumption that the Brinell hardness number divided by 6 is approximately equal to the Scleroscope number. According to the evidence of the present tests, the ratio of the Brinell hardness number appears to increase gradually from 5·5 for very soft material to about 8 for materials of over 700 on the Brinell scale. The number of tests on very hard material is, however, hardly sufficient for any definite conclusion to be drawn as to the magnitude of the change in the ratio with increasing hardness, and it is hoped to investigate the relation further in the future.

(2) *The preservation of the nature of the surface during the progress of the test.*

From the comparison of the figures in columns 3 and 4 (Table 2), in which are given the scleroscope numbers of the surfaces before and after test, it will be seen that the characteristic which distinguishes the sliding abrasion test from the rolling abrasion test is that the former does not cause any perceptible hardening of the surface under wear as the test proceeds, that is, the test is not made on deformed material, but on material in the state in which it existed before the test. Slight exceptions to this will be noted in the case of the five manganese steels in which the scleroscope number for the worn surfaces is on the average 7·5 per cent. greater than on

(*Continued on page* 699.)

TABLE 2 (*continued on opposite page*).

Test No.	Marks.	Condition of Material.	Analysis.						
			C.	Si.	Mn.	S.	P.	Cr.	Ni.
1	6	Hardened in oil at 850° C.; tempered in gas muffle at 600° C.	0·70	—	—	—	—	2·0	2·5
2	1010/2	Manganese Steel as forged.	1·36	0·36	13·10	—	—	—	—
3	1010/1	Do. quenched at 950° C. in water.	1·36	0·36	13·10	—	—	—	—
4	1968A	Do. Water toughened.	1·26	0·11	9·22	—	—	—	—
5	1010	Do. Do.	1·18	0·14	12·29	—	—	—	—
6	2055	Do. Do.	1·48	0·25	15·23	—	—	—	—
7	A	Carbon steel as rolled.	0·52	0·10	1·26	0·05	0·09	—	—
8	8	Do. Do.	0·50	0·19	0·94	0·07	0·07	—	—
9	11	Do. Do.	0·60	0·15	0·93	0·04	0·10	—	—
10	3123C	Do. Do.	0·75	0·20	0·84	0·04	0·05	—	—
11	2217	Do. Oil toughened.	1·62	0·15	0·29	0·02	0·02	—	—
12	1772A	Do. Do.	0·43	0·14	1·44	0·06	0·06	—	—
13	6B	Do. Do.	0·44	0·48	1·01	0·06	0·06	—	—
14	2250/958	Do. as rolled.	0·65	0·13	0·60	0·02	0·03	—	—
15	2250/955	Do. toughened.	0·65	0·13	0·60	0·02	0·03	—	—
16	2250/956	Do. Do.	0·65	0·13	0·60	0·02	0·03	—	—
17	720/1	Do. mild steel.	0·21	0·02	0·46	0·05	0·06	—	—
18	704/1	Do. mild steel mechanically hardened to 35 tons per square inch.	0·04	0·05	0·41	0·04	0·07	—	—

(*continued from opposite page* TABLE 2).

1	2	3	4	5	6	7	8
Brinell Test.		Scleroscope Test.		Sliding Abrasion Test		Ratio. Brinell Number Scl. No.	Ratio. Brinell No/Resistance to sliding abrasion.
Unworn surface.	Worn surface.	Unworn surface.	Worn surface.	Thickness removed mils. per 1,000 feet slip.	Resistance to sliding abrasion.		
420	420	67	68	0·7	140	6·3	3·0
277	284	44	46	2·2	45	6·3	6·2
219	230	34	39	2·1	48	6·4	4·6
203	—	30	31	2·0	50	6·8	4·1
206	—	30	32	2·1	48	6·9	4·3
228	—	34	37	1·9	53	6·7	4·3
234	237	41	41	1·3	77	5·7	3·0
228	228	36	35	3·9	26	6·3	8·8
252	248	40	39	0·9	110	6·3	2 3
273	282	50	50	0·8	125	5·5	2·2
346	349	62	61	0·5	200	5·6	1·7
216	—	37	37	2·9	35	5·8	6·2
222	—	37	38	3·2	31	6·0	7·2
235	—	41	42	1·1	91	5·7	2·6
337	—	61	61	0·3	330	5·5	1·0
330	—	58	58	0·2	500	5·7	0·7
115	116	21	24	5·3	19	5·5	6·0
149	144	37	37	5·5	18	4·0	8·3

TABLE 2 (*continued from previous page*).

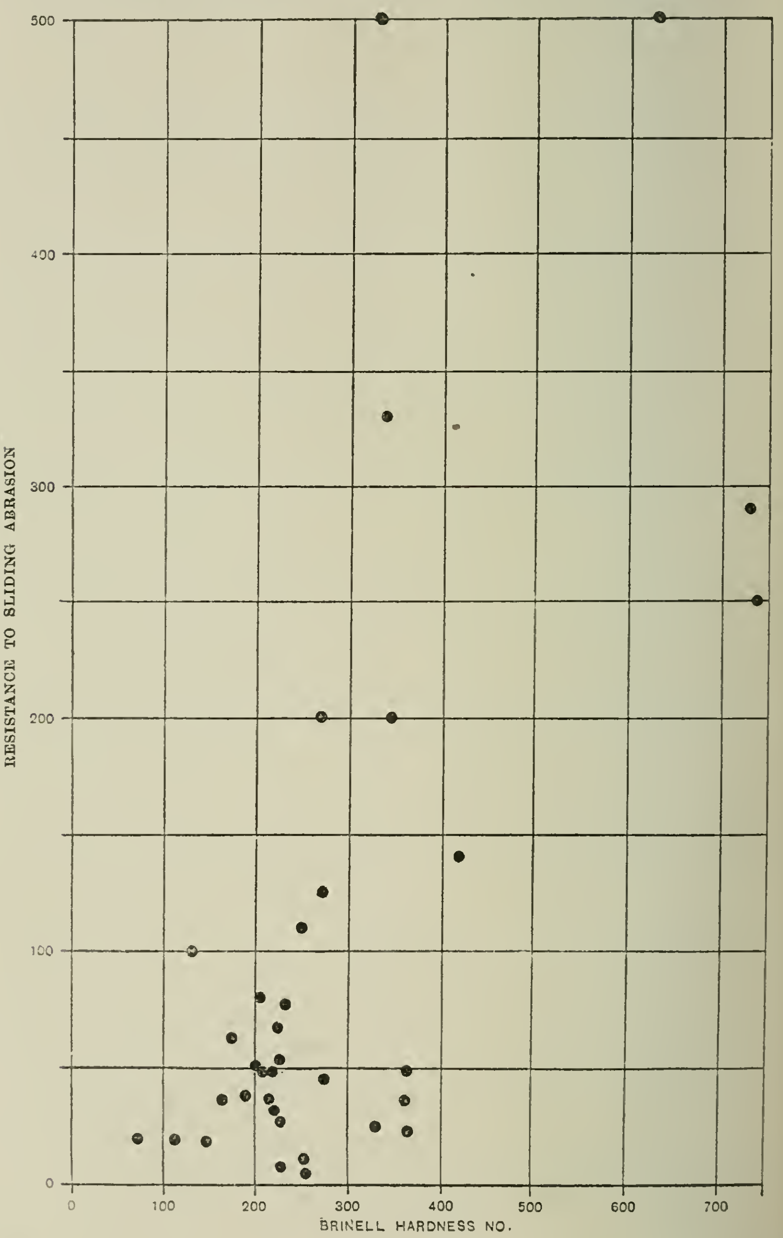
Test No.	Marks.	Condition of Material.	Analysis.						
			C.	Si.	Mn.	S.	P.	Cr.	Ni.
19	A1629	Rail steel, as rolled.	0·45	0·11	0·97	0·05	0·05	—	—
20	B1631	Do. Do.	0·52	0·15	0·75	0·01	0·03	—	—
21	1908D	Self - hardening steel, air hardened.	0·60	—	—	—	—	3·5	W 16·0
									Ni.
22	1109D	Special steel, water toughened.	0·60	0·62	5·0	0·05	0·06	—	15·0
23	3137D	Do. Oil toughened.	0·66	0·15	0·23	0·02	0·03	2·5	2·8
24	1795E	Do. annealed.	0·35	0·08	0·66	0·05	0·03	1·75	3·7
25	2297	Do.	0·57	0·20	0·76	0·05	0·06	1	—
26	3109	Do.	0·33	0·07	1·21	0·05	0·06	1·25	—
27	1795G	Do.	0·20	0·04	0·38	0·05	0·05	2	4
28	3121	Do.	0·31	0·05	1·18	0·05	0·08	1	3
29	3102	Do.	0·18	0·03	0·48	0·03	0·03	0·5	2·5
30	68	Gauge steel, hardened.	1·02	0·31	0·45	0·02	0·03	1·43	0·03
31	4789	Do. Do.	0·86	0·18	1·34	0·02	0·03	0·05	—
32	B.D.	Do. Do.	0·97	0·12	0·26	0·01	0·02	0·14	W 1· V 0·
33	C.	Do. case hardened.	0·28	0·05	0·91	0·08	0·06	0·04	—
34	F.	Do. unhardened.	0·72	0·12	0·22	0·01	0·07	4·16	W-12· V- 0·
35	719	Admiralty bronze.							
36	708	Phosphor bronze.							

(*concluded from opposite page* TABLE 2).

1	2	3	4	5	6	7	8
Brinell Test.		Scleroscope Test.		Sliding Abrasion Test.		Ratio. Brinell Number / Scl. No.	Ratio. Brinell No./Resistance to sliding abrasion.
Unworn surface.	Worn surface.	Unworn surface.	Worn surface.	Thickness removed, mils. per 1,000 feet slip.	Resistance to sliding abrasion.		
190	—	34	36	2·65	38	5·6	5·0
206	—	37	38	1·25	80	5·6	2·6
627	—	103	103	0·2	500	6·1	1·3
175	—	26	29	1·6	63	6·7	2·8
364	—	60	61	2·8	36	6·1	10·1
255	—	45	46	9·6 & 26·6	10 to 4	5·7	25 to 64
271	—	47	47	0·5	200	5·8	1·4
226	—	41	41	1·5	67	5·5	3·4
366	—	61	63	2·0 & 4·6	50 to 22	6·0	7·3 to 16·6
332	—	55	56	4·2	24	6·0	13·8
165	—	28	29	2·8	36	5·9	4·6
720–740*	—	107	106	0·35	290	6·8	2·5
675–695*	—	100	101	0·1	1,000	6·8	0·7
725–750*	—	108	112	0·4	250	6·8	3·0
—	—	110	111	0·2	500	—	—
228	—	37	40	14·7	7	6·2	32·6
75	82	17	26	4·9	20	4·4	3·8
131	137	26	29	1·0	100	5·0	1·3

* Values approximate owing to flattening of ball.

FIG. 8.—*Comparison of Brinell Hardness No. and Resistance to Sliding Abrasion.*



the unworn surfaces. This effect, however, is not surprising, considering the marked susceptibility of these steels to hardening under pressure which has been noted in the rolling abrasion tests, in which the hardness numbers were practically doubled by the action of the rolling, and also considering the high value of the load which was adopted due to the considerations already stated.

An interesting confirmation of Sir Robert Hadfield's explanation of the high wearing properties of the manganese steels under rolling abrasion, as being due entirely to the hardening of the deformed surface, is seen from the results of Table 2, since in the present tests the resistance to sliding abrasion of the manganese steels is fairly low.

In order to obtain a further demonstration of the property of this test, a special set of observations were made on a sample of mild steel (No. 720/2) and a sample of manganese steel (No. 1010/2) by measuring the wear of the (same) surface after successive equal intervals of time. If there were any gradual hardening effect on the surface, this would reveal itself in the gradual reduction of the rate of wear with time. As will be seen from the results given in Table 3, no action of this kind can be detected.

TABLE 3.

Material.	No. of Revolutions.	Wear in mils. per 1,000 ft. slip.	Resistance to sliding abrasion.
Mild Steel, No. 720/2.	0–10,000	5·5	18
	10,000–20,000	5·8	17
	20,000–30,000	5·8	17
	30,000–40,000	6·1	16
Manganese Steel, No. 1010/2.	0–10,000	2·0	50
	10,000–20,000	2·0	50
	20,000–30,000	2·0	50
	30,000–40,000	2·2	45

(3) *The Relation between the Resistance to Sliding Abrasion and the Brinell Hardness Number.*

The ratio of the numbers expressing these characteristics are given in column 8 of Table 2 (pages 694–7), and the results are plotted in Fig. 8 (page 698).

In order to express in a concise form the extreme variations in resistance to sliding abrasion corresponding to any given Brinell hardness number, which have been found in the miscellaneous

TABLE 4.

Brinell No.	High Resistance to Sliding Abrasion.		Low Resistance to Sliding Abrasion.	
	Test No.	Resistance to abrasion.	Test No.	Resistance to abrasion.
165–175 . .	22 (175)	63	29 (165)	36
190–206 . .	20 (206)	80	19 (190)	38
226–228 . .	26 (226)	67	34 (228)	7
228–235 . .	14 (235)	91	8 (228)	26
255–271 . .	25 (271)	200	24 (255)	4 to 10
330–332 . .	16 (330)	500	28 (332)	24
346–364 . .	11 (346)	200	23 (364)	36

selection of materials tested for the present investigation, the figures given in Table 4 have been abstracted from Table 2. These give the maximum and minimum values of the resistance to sliding abrasion for materials whose Brinell hardness number is approximately the same.

Closer examination will show that it is the special steels which are responsible for the enormous variation in resistance to sliding abrasion, which is given in Table 4, and that in the case of ordinary carbon steels the fluctuation is much less. As regards the latter steels, it may be said that a high Brinell hardness number will

generally indicate a high resistance to sliding abrasion, but there are exceptions to this rule.

As regards the general results of the investigation, it is clear that the Brinell hardness numbers of a miscellaneous selection of steel are not a safe guide in predicting their relative resistances to wear. This result is in general agreement with those obtained by Robin, Nusbaumer, and Saniter, with other methods which have been referred to in the President's Memorandum (Appendix I).

The Report is illustrated by 8 Figs. in the letterpress, and is accompanied by 4 Appendixes.

APPENDIX I.

MEMORANDUM ON TESTS OF HARDNESS AND RESISTANCE TO WEAR.

By W. CAWTHORNE UNWIN, LL.D., F.R.S.

Hardness is a property of materials very important in many cases, but as to which there is not an agreed definition, nor is any one method of measurement generally adopted. Most commonly, by *hardness* is meant the resistance a material opposes to penetration by another body.

The earliest scale of hardness is that proposed by the mineralogist Moh. He selected ten natural substances, arranged so that each would scratch the substance next below it in order, and be scratched by that next above it. On this scale talc had a hardness 1, and diamond a hardness 10. A copper coin had a hardness 3, ductile iron a hardness 4·5, a file a hardness 6·5. It is a defect of the Moh scale that materials selected by him vary somewhat in hardness in different specimens.

*Professor T. Turner's Scratch Test.**—A balanced lever capable of moving vertically on a knife-edge and of being rotated is graduated and provided with a sliding weight. The free end carries a diamond point which can be moved over the surface of the material to be tested. The graduations are such that a movement of the sliding weight over one scale division corresponds to 10, 20, 30, or 40 grams at the diamond point, according to the sliding weight used. The surface of the specimen is smoothed and polished with flour emery, and oil. The weight in grams at the diamond point which produces a decided scratch is taken as the hardness number. There is some skill in determining this. Turner suggests making several scratches with diminishing weights, and taking for the hardness number the mean between the smallest weight which produces a quite definite and visible scratch, and the greatest weight which does not produce a visible scratch. Turner found the following hardness numbers:—lead 1, annealed copper 8, softest iron 15, mild steel 21, tyre steel 20–24, hard cast scrap-iron 36, hardest cast-iron 72.

To make the test more definite, Martens defined the hardness number as the weight in grams which would produce a scratch 0·01 mm. in width. Several scratches are made and the loads and widths plotted. With a diamond point ground to an angle of 90° Martens obtained the following hardness numbers:—lead 17, copper 34–40, soft steel 71–77, hard steel 138–141.

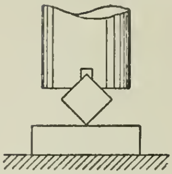
Indentation Methods.

Various investigators have used an indentation test for determining hardness, and such a test is specially suitable for ductile metals. The indenting tool has been a knife-edge, cone, or pyramidal point. The weight causing a given depth of indentation, or the reciprocal of the depth of indentation with a given weight, have been taken as the measure of hardness.

Foeppl placed two cylinders of the material to be tested at right angles and pressed them together in a testing machine. The

* Proceedings, Birmingham Philosophical Society, vol. v, part 2, 1886.

pressure per unit of flattened surface is taken as the measure of hardness. The method is good, but the preparation of specimens is rather costly.



The author * used as an indenting tool a small square bar of hardened tool steel with edges accurately ground. The material tested was formed into a bar 2 inches $\times \frac{1}{2}$ inch $\times \frac{1}{2}$ inch. The tool was pressed into the specimen in a testing machine, and the load P in tons and corresponding depth of indentation i in inches were noted. Then $C = P/i$ was taken as the hardness number. The hardness number varied from 195 to 256 for different steel rails having from 0·329 to 0·415 per cent. of carbon. It was found that the ratio (tensile strength)/(hardness number) was nearly constant. For the series of (13) rail steels its mean value was 0·181 (ton and inch units).

The Brinell Hardness Test.—In 1900 Mr. J. A. Brinell † described an indentation test for hardness, the indenting tool being a spherical ball. Some convenient forms of apparatus for applying this test have been devised by Martens and others, and it is now very generally used. Let P be the pressure in kilograms, D the diameter of the ball, d the diameter and h the depth of the indentation, all in millimetres. Then

$$h = \frac{1}{2}(D - \sqrt{D^2 - d^2}) \text{ millimetre,}$$

and the area of the spherical surface of the indentation is

$$A = \pi D h = 1 \cdot 571\ D (D - \sqrt{D^2 - d^2}) \text{ square millimetre.}$$

Then Brinell takes the hardness number to be $H = P/A$.

To determine H, the load P and the corresponding value of either h or d must be observed. It is simpler to measure h, but it has been found generally more convenient to measure d with a micrometer microscope. More recently a glass slide with two

* Proceedings, Institution of Civil Engineers, vol. cxxix, 1897.

† Sur les epreuves à bille en acier. Communications devant le Congrès International des Methodes d'Essai des Materiaux, Tome II, p. 81. Paris, 1901. Materialienkunde, IX, 318 ; X, 54 ; XI, 6.

inclined engraved lines has been used. For strictly comparable results fixed values must be taken for D and P. For steel it is usual to take P = 3,000 kilograms and D = 10 millimetres. For softer materials Brinell suggests that P should be taken = 500 kilograms, and gives a Table of the corresponding values of d with 3,000 and 500 kilograms.

Grard, in a Paper before the International Association for Testing Materials, at New York, discussed some of the sources of error in the Brinell test. Ludwig suggested the substitution of a cone for the ball.

Brinell noticed a close correspondence between the hardness number and the tensile strength of a material. For Fagersta steel the ratio of tensile strength to hardness number was very approximately 0·346 (kilogram and millimetre units). Dillner found the ratio for hardness numbers below 175 to be 0·354 and for those above 0·324. Charpy in the same cases found the ratios 0·351 and 0·336.

The Shore Scleroscope is a rebound instrument for testing hardness, patented by an American engineer. A full description of the apparatus and its applications is found in a pamphlet obtained from The Coats Machine Tool Co., Caxton House, London, S.W. The essential part is a diamond-faced hammer or tup, weighing about 40 grains, which is allowed to drop on the material to be tested from a fixed height, and the height of rebound is observed against a graduated scale. Ingenious arrangements are provided for lifting and releasing the hammer by air-pressure from a bulb. The indenting part of the hammer is convex, and it appears to be essential that a permanent indentation should be made in the material tested. The test therefore appears to be in fact an indentation test, the rebound being diminished by the amount of work expended in indentation. The area of the indenting point is stated to be $\frac{1}{2500}$ of a square inch. A magnifier hammer with larger point is used for very soft materials. The surfaces tested are smoothed but not polished. The scale is graduated into 140 equal divisions and medium hard hardened

steel gives a hardness number 100. It is stated that the Brinell hardness number divided by 6 agrees approximately with the Shore scleroscope number.

It appears from the relation of the tensile strength and indentation hardness that the latter is simply, at any rate for steels, a strength test. This must have been a surprise to those seeking a test for hardness, who no doubt regarded it as a separate property of materials, although of course the fact that hardness and strength both increase with the percentage of carbon was well known. The rebound test of balls for ball-bearings appears to be a test of elasticity not of hardness, the pressure not being great enough to cause permanent deformation.

Resistance to Wear.

In a large number of cases hardness in a material is desired on the assumption that the harder a material is the greater will be its resistance to abrasion and wear. But the point requires separate investigation. It will be found that hardness as determined by the methods described above and resistance to abrasion or wear are not in any exact relation.

Various methods of testing resistance to wear or abrasion have been tried. Bottone used a soft iron disk rotating at a constant speed and pressed with a constant force against the material tested. The time required to produce a cut of a definite depth was taken as the measure of resistance (*Chem. News*, xxvi, 215, 1873). M. Felix Robin (Iron and Steel Institute, 1910) used cylindrical specimens, 50 mm. in diameter, rubbed under a definite pressure on papers covered with abrasive powders. M. Derihon devised a machine in which a lever presses the specimen on the circumference of a polished wheel turning at high speed in an oil bath. The speed of the wheel was 3,200 revolutions per minute, and each test was continued for two million turns. The wear was measured in thousandths of a millimetre. Professor M. Gary (Mitt. aus dem Kön. Materialprufungsamt, Berlin, 1904, 103) has used the abrading power of a sandblast to determine resistance to wear, chiefly of natural stones, artificial minerals, and timber.

Mr. Saniter's Comparison of Different Tests of Hardness and Wear.

Mr. E. H. Saniter, of Rotherham, in a Paper read at the New York Congress of the International Association for Testing Materials, 1912, gave the results of a very interesting investigation of the results of determining hardness and wear of the same materials by different methods. He used two methods of determining hardness, the Brinell test and the Shore sclerometer test. For the steels examined both methods place the steels in the same order with one exception. But the ratio of the Brinell number to the Shore number shows some variation.

Mechanical wear, in Mr. Saniter's view, implies the removal of a portion of the material in small particles by friction. This may occur (*a*) by pure abrasion; (*b*) by lubricated sliding friction; (*c*) by dry rolling friction. He points out that vibration enormously increases the amount of wear, and that it is necessary to check the effect of vibration of the testing machines by testing a standard material at frequent intervals.

(*a*) *Pure Abrasion.*—M. Robin tested wear by using emery and other abrasive papers, and at the same time determined the Brinell hardness number. It appeared that there was no relation between the Brinell hardness number and the resistance to wear tested by M. Robin's method. Yet that method seems a reasonable one for determining the resistance to abrasion.

(*b*) *Lubricated Sliding Friction* has been investigated by E. Nusbaumer using the apparatus of M. Derihon, which consists of a hard steel disk running in oil on the edge of which a specimen is pressed. The Brinell hardness number was also determined, but it has no relation to the resistance to wear found by the Derihon test. Yet it seems that the latter should give correct results as to wear by sliding friction.

(*c*) *Dry Rolling Friction* was tested by a wear machine designed by Mr. Saniter. A revolving test-piece drives by friction on its top side the inner ring of a loaded ball bearing. The results on 0·7 per cent. carbon steel subjected to various heat treatments

show a general relation to the corresponding Brinell number. There are however two exceptions. In another series of tests of different carbon steels treated alike, there is also a distinct relation with one glaring exception. In a third series of tests on alloy steels the relation between the Brinell number and the Saniter test of wear entirely breaks down.

But the reliability of this wear test is emphasized by the test on Hadfield's manganese steel which gives, with a low Brinell number, the best wear number of all the steels tested. The excellent wearing properties of manganese steel rails is well known.

The importance to the Committee of the results in Mr. Saniter's interesting Paper is this. It is probable that the firm who suggested to the Institution an investigation of a hardness test for case-hardened bearings and hard cast-iron for cylinders really were seeking a test for resistance to wear and tear, and confused this with a test of hardness as generally understood.

APPENDIX II.

MEMORANDUM ON HARDNESS.

By Sir ROBERT A. HADFIELD, D.Sc., D.Met., F.R.S.

1. When inquiry is made as to what is meant by hardness, it is found this is a somewhat indefinite and vague term. When "hardness" is spoken of, no more definite statement is intended than if, for instance, the term "strength" is being discussed.

2. If anyone were asked to measure the strength of a certain specimen, he would immediately ask "under what conditions?" He would then be told that what was required was, for instance, what pressure or tension it would stand without extending (or being compressed) more than 10 per cent.; or what load before it fractured?

3. Hardness is no more definite than this. Hardness, in other words, is not a specific property of a material. To make it specific it must be hedged round with definite instructions as to the limit to which the material must be deformed. A definite figure cannot be assigned for any property of a material unless this property is a specific one.

4. The writers' conception of hardness is simply "resistance to deformation." Now the resistance to deformation of any material depends on how much it is deformed—as a rule, the more it is deformed the greater is the load required (for some viscous materials, such as pitch, the deformation proceeds continuously under a constant small load). Further, the rate of increase of load with deformation varies in different materials.

5. It is useless, therefore, to fix an arbitrary amount of deformation and measure the load, for of two materials A and B, A may require less load than B to deform it 5 per cent., but B may require less load than A to deform it 50 per cent. Also, brittle materials will not deform at all.

6. The efforts to establish an academic idea of hardness are, therefore, limited to the resistance offered by a material free to flow, up to the point when it is just permanently deformed, which in the case of brittle materials, of course, means fractured. In elastic material this academic definition of hardness is nothing more than the "yield-point." To measure the hardness one has, therefore, only to measure the "yield-point."

7. This definite and specific property seems to be the real "fundamental hardness," and indeed the whole hardness of brittle materials.

8. According to this criterion manganese steel is of a soft nature. Its yield-point is low, a very small load producing permanent deformation. From this standpoint manganese steel, unless its character is altered by deformation, is really soft, yet in the ordinary acceptance of the term this material is considered very hard. Why is this? The explanation is that the ordinary term involves a loose conception of more or less (no definite amount) deformation, and the "hardness" is that of the more or less

deformed material. Manganese steel is an extremely hard wearing material, in spite of its natural softness, because the act of abrasion deforms the material, locally its resistance to further deformation increasing enormously thereby, and the material actually abraded off is not manganese steel in its natural state, but is the quite different material, *deformed manganese steel.* Manganese steel is soft—deformed manganese steel is hard. In a pulled tensile bar over 500 ball number has been obtained, and yet the material is just as non-magnetic as before, showing this physical change has taken place without interfering with its peculiar non-magnetic qualities. Deformed manganese steel has its own specific properties, quite distinct from manganese steel in its natural state or manganese steel subjected to other heat treatment than water toughening. Somewhat similar remarks apply to bronzes and other materials.

9. This is really the crux of the difficulty in trying to assign a value to the practical term loosely known as hardness. It is not sufficient, however, in all cases to measure the resistance of the material to deformation at the point of rupture. In the first place, it is not possible to deform any specimen of material so that at all points where fracture occurs the amount of deformation is uniform. There seems no way of measuring the resistance to deformation (that is, the true "hardness") of deformed materials except in an approximate manner. In the second place, the action of deformation in the practical use to which the material is applied, is to deform some parts more than others, in no regular and definite manner.

In scratch tests a comparison is made between the breaking stress of two substances; as the pressure is being applied, stress is applied equally on the two materials, and they deform accordingly, until one of them reaches its limit of deformation, breaks off, and is then said to be "scratched" by the other. The other is "harder" by virtue of the fact that its breaking stress is greater, and the method places materials in a series of ascending "hardness," that is, ascending "breaking stress." Some idea of the relative "hardness" of materials, for example, in Moh's scale, might therefore be determined (only approximately as mentioned above—due to

unequal strain and difficulties due to cleavage) by tensile or shear tests, measuring the breaking stress per unit area of the fracture.

Scratch tests, therefore, while probably enabling a definite *comparison* to be made of the true deformation hardness, do not give a numerical value.

10. Now all this applies only to ductile materials. Brittle materials which do not deform clearly cannot have this complication of deformation hardness. In these cases, therefore, a practical measurement of hardness, which in reality is the stress at the yield-point, is possible.

There is here, however, a still further complication. Viscous materials, like pitch, while requiring in the ordinary way a definite stress to produce deformation and rupture, if sufficient time is allowed, will deform under the slightest stress. The definition of natural hardness should, therefore, include an arbitrary time element, and this is a matter of practical arrangement. The time rate would theoretically be infinitely slow, but this would destroy the practical value of the definition, as it would make pitch almost infinitely soft like a limpid fluid, while to all practical intents it is rather hard. The time rate of loading must, therefore, be within the ordinary limits of practical testing. It might be stated that many of the "elastic" materials behave somewhat like pitch.

11. It will be readily understood from the above what relation the results obtained from current methods of testing hardness have to the true hardness of materials. Each of these methods in the case of ductile materials deforms the material in its own particular fashion. It deforms one part of the material more than another, and the relative degrees of deformation are quite different according to the method employed. For example, in abrasion or scratch methods, some portion of the material is completely detached, that is, deformed to the point of rupture; in indentation tests the material is generally not broken; in each case the remaining portions are deformed in varying degrees from nil to the maximum, and not in equal gradients. How, therefore, can it be expected that these methods should agree among themselves, or that the results should represent some specific property of the material? Further, with

indentation tests, even with tests by the same method, on different materials the same defect exists. How, therefore, can any of these methods give a true numerical relation between the hardness of two materials, so as to say, for instance, that one material is twice as hard as another?

12. Summing up, the situation seems to be:—

(*a*) Hardness as generally understood is a loose term, not representing any specific property, but "resistance to deformation."

(*b*) The greater resistance in general of deformed materials to deformation (or deformation hardness) over that required to produce the first permanent deformation in the same undeformed material (or natural hardness) is involved to an indefinite extent in this term.

(*c*) No single value can therefore be assigned to the hardness of the material in this general sense. It can only be expressed by a complete stress-strain curve.

(*d*) The "natural hardness" can be measured, and is the "yield-point stress." Even this is subject to disability in the case of viscous materials like pitch.

(*e*) There seems to be no satisfactory method of determining "deformation hardness"—that is, the resistance to deformation of material deformed practically to its fullest extent. Scratch methods enable comparisons to be made of this more or less definite property, but do not give a numerical value.

(*f*) Other methods professing to measure hardness, measure the resistance of material deformed to varying amounts in different parts, and cannot therefore be expected either to agree among themselves or to give a true numerical value for the hardness.

(*g*) Brittle materials in which little or no deformation is possible are not subject to this complication of deformation hardness. On the other hand, they cannot be indented without fracture (cracking), and the utility of indentation methods is destroyed in their case.

APPENDIX III.

DEFINITION OF HARDNESS.

By A. E. H. TUTTON, D.Sc., F.R.S.

The hardness of a solid substance may be defined as the resistance offered by a smooth surface of the substance to abrasion. It is measured by the capability of the substance being just abraded or scratched by contact with a sharp fragment of another substance of slightly greater hardness, and of which the precise degree of hardness is known with reference to a conventional scale. Particles of the softer substance are torn away by the harder, their cohesion being overcome. Hence, hardness is intimately connected with cohesion. If the solid substance is crystallized, the hardness varies slightly with the direction within the crystal, as cohesion in a crystal is in general dissimilar in different directions; thus hardness is always lower along a direction of cleavage than along the direction perpendicular thereto. For cleavage planes are planes of points of the crystal space-lattice which are most densely strewn with points, and in which cohesion is, therefore, a maximum, while successive parallel planes of points (all parallel to the plane of cleavage) are the most widely separated from each other, the points being farthest apart in the direction at right angles to these planes; the cohesion is, therefore, a minimum perpendicular to the plane of cleavage. The particles are, consequently, more readily torn off from a cleavage face than from any other face of a crystal. Moreover, high specific gravity (density) is generally accompanied by great hardness. For (considering the case of the perfect solid—a crystal), the points of the space-lattice being the closer together the denser the substance, greater difficulty is naturally experienced in overcoming their cohesion, in accordance with the usual laws governing the attractive forces between particles.

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Attention may also be drawn to an interesting series of Papers, on the Hardening of Metals, which were read in May 1915, and printed in the Transactions of the Faraday Society. The contributors include Sir R. Hadfield, Sir G. Beilby, Professors Arnold, Cohen, Edwards, Howe, and Turner; Drs. Desch and Lowry; and Messrs. Humfrey and Parker.

Papers dealing with the hardness of the zinc-copper, zinc-aluminium, antimony-lead, and other alloys will be found in the Journal of the Institute of Metals.

Discussion in London.

The President said that the Report was a very interesting one, but he did not propose to criticize it at present. A Memorandum by himself (the President) appeared as an Appendix to the Report, consisting of a short historical account in regard to different methods of testing hardness, which he wrote for the Committee at the beginning of its work, but it was not the usual practice to read Appendixes at the Meetings of the Institution.

Sir Robert A. Hadfield, F.R.S. (Member of Council), in opening the discussion, said he was very pleased to do so because the Report was a most valuable one. As the results given in the Report of the Committee spoke for themselves, he only proposed to add a few general comments. Here and there he had had a little to do with the Report, and it would be to some extent rather

like criticizing his own work if he were to add anything more than this. He took the opportunity of saying that a considerable debt of gratitude was owing to Dr. Stanton for the able manner in which he had performed his side of the work for the Committee. Because he happened to be one of its Members, he was sure he would not be misunderstood when he said that it seemed to him the research had been carried out under particularly favourable conditions, conditions which might well be imitated in other Reports of the kind. A body of scientific and practical men appointed by the Council of the Institution had met together from time to time, drawn up a programme, and carried out the work in a manner which had given important practical results. It should also be added that the President had been particularly active and had made most useful suggestions, as he always did, which had greatly increased the value of the work done. Happily they had also the right man at hand in the person of the Reporter to carry out the experiments decided upon. He felt that the members as a whole would agree that there could not have been a better combination in order to obtain theoretical and practical results. In the working out of the experiments they had, too, a special proof of the advantage of having the National Physical Laboratory in their midst. It was more than probable that, without its ready co-operation and help, the results would either not have been obtained at all or would have taken a longer time to carry into effect.

Some of the results put forward in the Report were entirely novel and probably new to many engineers and metallurgists; in fact, some of them were, he believed, presented for the first time. For example, it was not generally known that manganese steel, now so widely used, owed its wonderfully high wear-resisting properties not to the inherent quality or composition of the alloy, but to the following curious properties which he noticed many years ago and which were also noticed by the late M. Osmond. Strange as it might seem, the great advantages obtained in the use of manganese steel, for certain special purposes, such as the faces of crusher jaws and the wearing parts of crushing machinery, also

tramway and railway work, did not arise directly from the composition of the material or its treatment. He did not think that this was generally known. It was neither to the composition, nor to the analysis, nor to the treatment that the peculiar properties of that very strange alloy were due. In other words, manganese steel, as such, was really quite a "soft" product of great toughness, possessing only about 200 Brinell ball hardness number. The very moment, however, that deformation produced by crushing or rolling was applied, the skin of the surface was immediately changed into quite another structure of an entirely different and much greater hardness, passing from, as he had already said, about 200 ball hardness—(wrought-iron was about 80 and mild steel was about 120)—as forged and toughened into 300 to 500 Brinell ball hardness number. Its hardness in the lathe was also due to that fact, that was to say, as the material was cut it became hard, so to speak, artificially; in other words, it could not be cut without producing deformation. Then the moment hardness was produced, it could not be machined in a practical way. Only indirectly was this strange quality due to composition or heat treatment; but chiefly to the strange property of becoming hard when deformed. He had with him a portion of a manganese steel jaw used for a stone-breaking machine. The hardness of this specimen as originally prepared was 200 ball hardness number all the way through. By use it had changed its hardness on the surface to anything from 300 to 500 ball hardness. It was difficult to account for this strange faculty of changing materially its hardness. There was no change in the composition of the steel or that would lead anyone to imagine that the steel could show so enormous a difference—a change, so to speak, almost equivalent to that from a state of soft grey iron to that of chilled iron. The effect was not one of temperature, only of deformation.

As regards changes generally by deformation, no one had put that idea forward more clearly than the President. For the reasons just mentioned, jaw faces of manganese steel for crusher machines when first put to work appeared to wear no better than ordinary steel, but as soon as the surface, by pressure, friction, or otherwise,

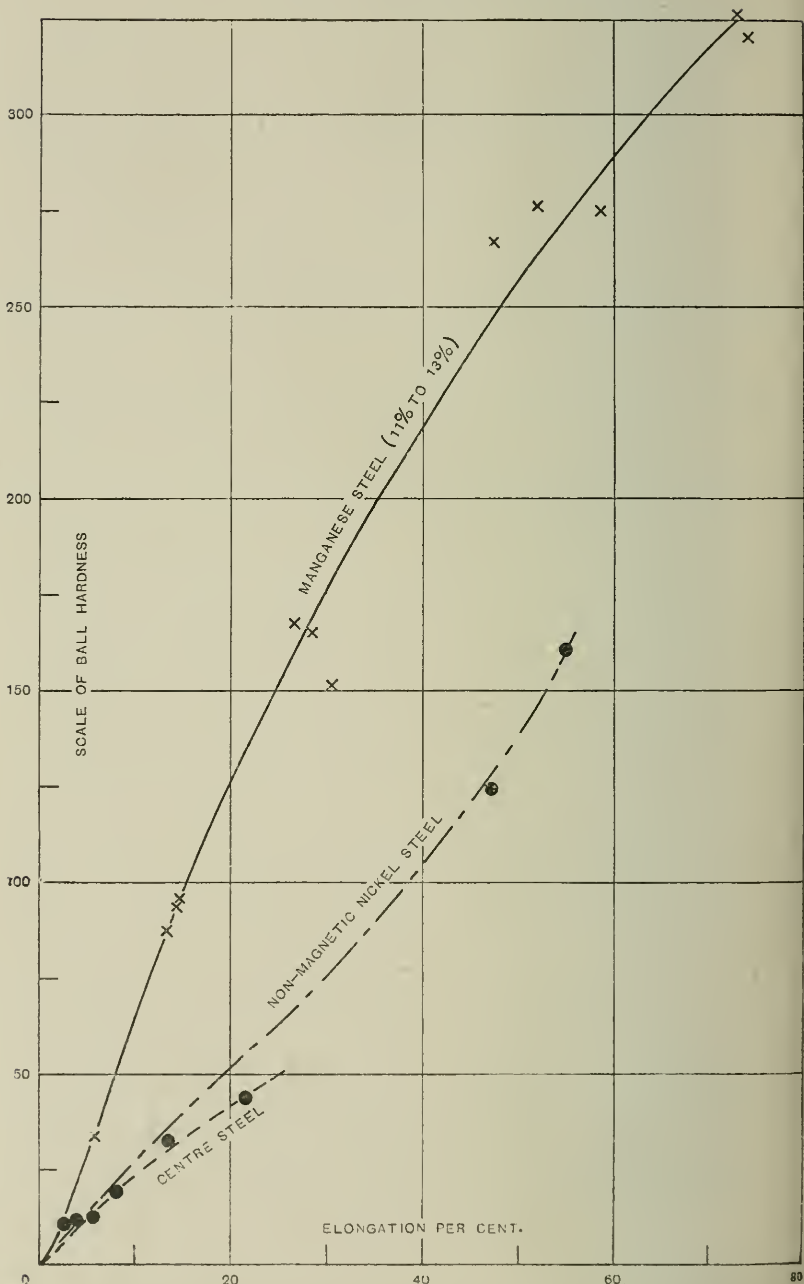
had been glazed over, the hardness jumped up, and this continued. The remarkable resistance to wear which the material then possessed was of the greatest practical advantage, for as the surface hardness wore away, immediately underneath another hard skin formed, and so the process was repeated until, in some cases after many years' use, the thickness of the wearing portion of the article was used up.

To put the explanation in another way, the material might be said to be self-hardening at natural temperatures—that is, without heating, unless the amount of friction or deformation set up generated a certain quantity of heat. That was, however, hardly likely, or at any rate such influence in itself would not be great. The curious changes noticed were due more to pressure or deformation rather than to increase of temperature. The immediate surface affected was only at first very thin, but it gradually increased until the material offered the desired resistance to wear and the wonderful durability noticed was obtained. As Dr. Stanton quite correctly put it, hardening of the deformed surface was brought about and the quality of the material, which, in its first stage—that is, in the toughened condition—offered but little more resistance than ordinary steel to sliding abrasion, was changed. In other words, pressure must also be present to bring about the change. Without that peculiar quality manganese steel would be, for such particular purposes, of little more value than ordinary steel of hard grade. He specially referred to that fact because it was another proof of how the scientific man discovered "things" by accuracy in working. Dr. Stanton knew nothing of that peculiar property of manganese steel; in fact, he (Sir Robert) had not thought of telling him about it at the time when the various specimens were prepared and sent to his laboratory. Dr. Stanton, however, discovered it, as would be seen from the results given by him and referred to on page 699 of the Report. That property, therefore, was still another peculiarity of manganese steel added to its curious non-magnetic and other strange physical properties. Fig. 9 (page 728) showed the increase of ball hardness produced by the tensile stretching of manganese steel as compared with carbon and nickel steels.

Another important fact was shown in the experiment on page 684,

(Sir Robert A. Hadfield.)

FIG. 9.—*Increase of Ball Hardness by Stretching.*



namely, that hardened steel, after being slightly tempered (Specimen No. 8986–1/2), was positively harder than steel which was not so treated, and the elastic limit was also greater. Possibly that was due to some slight change in the structure of the crystals, which, owing to that slight tempering, adjusted themselves. He was especially investigating that point in other directions, for which that very peculiar characteristic might be of service. One important conclusion to be drawn from the experiments was to show how little was known of hardened material and its qualities. In that new direction they were only just commencing to accumulate knowledge. Each special firm had generally its own way of arriving at the desired qualities and of explaining them when so obtained. In many cases, however, the conclusions were mostly empirical. It was therefore necessary that all concerned should set to work to improve their knowledge in the important new field of the quality of hardened steel, and he would ask those interested to try and find some way of helping the accurate determination of the hardness of hardened steel. At present, after reaching what was often termed glass scratching hardness, they were still very much in the dark. Glass scratching hardness indicated a ball hardness number of about 600. Below about 600 it would not scratch glass, but above 600 it would. The whole of the industry owed a deep debt of gratitude to Brinell, the great Swedish metallurgist, from whose labours they were greatly benefiting at the present day. In the production of automobile parts, aeroplane engines, projectiles and armour plate, and a variety of other purposes, it was necessary constantly to use the Brinell test. Speaking of his own works, thousands of determinations were made a week on comparatively large articles, and in many other cases where small articles were produced.

It was entirely owing to Brinell that manufacturers were able to measure the hardness and speak of it with some fairly correct degree of accuracy. Brinell, in his valuable Papers presented to the Iron and Steel Institute many years ago, stated that he could determine up to about 800 ball hardness—200 points higher than that at which steel commenced to be what was called "dead hard." Although his process was most excellent and could not be spoken

of too highly, for steel and other material possessing ordinary ball hardness numbers up to, say, about 600, on exceeding this it was nevertheless somewhat difficult and tedious, giving results often only approximately correct. All interested, therefore, would be greatly assisted if those making apparatus and special instruments relating to the determination of hardness would study methods of enabling hardnesses varying from 600 to 800, or even higher, to be obtained quickly and correctly. He had never heard of anything higher than 780 Brinell number, and that was not with an alloy steel but plain carbon steel. Indeed, plain carbon steel seemed in some ways to be able to take a rather higher degree of hardness than special steels—he referred, of course, to extreme hardness. If the Council would permit, he would be very glad to offer an inducement in the form of a prize, either monetary or a medal, to anyone within the Empire who could find an accurate way of determining hardnesses of the nature mentioned. The methods chiefly used at present were: (*a*) Brinell apparatus, determining by pressure and using hardened steel balls of different diameters, with standard pressures of 1,000, 2,000 and 3,000 kg.—in fact, up to 5,000 in some cases. In his own case, if it were desired to determine extreme hardness, pressures up to 5,000 kg. were used. That pressure was, of course, enormous, seeing the small area acted upon, and it was difficult to get balls that would stand, but during the last few years this had been achieved with excellent regularity.

It had to be borne in mind that, in trying to determine such hardnesses, the material dealt with was not tough but comparatively brittle, and cracks might supervene. It was divulging no secret to say that not many years ago his own firm believed they had obtained an excellent way of determining the requisite hardness for the points and shoulders of projectiles. A small number of projectiles had been tried, with satisfactory results. A few weeks later, however, it was found that the whole of those projectiles were cracked. The cracks were so minute that they might well have escaped detection. Such a projectile might be a serious source of danger. That showed the great care that was needed in opening out a new line of testing.

The second method (*b*) consisted of rebound tests such as were used in the Shore scleroscope method; also the Pellin, a French method. The third method (*c*) was the scratching apparatus, represented by the useful apparatus invented by Professor T. Turner, of Birmingham. None of those methods, however, were altogether satisfactory or met the requirements in the direction he had mentioned, so he hoped that some investigator would persevere and give us the much required apparatus for determining what might be termed a high hardness. The Pellin apparatus, which was not very well known in England, was useful for determining the hardness of very thin material; neither by means of the scleroscope nor by means of the Brinell ball was it possible to determine easily the hardness of such material, as the pressure of the ball distorted the thin steel too much, nor was the scleroscope test of much value in such cases. With the Pellin apparatus, however, tests of thin material were feasible. The apparatus had been recommended to him by Professor Henri Le Chatelier, and the results obtained were exceedingly satisfactory, quite comparable with those of the Brinell and other existing methods on thicker materials. In conclusion, he desired to express the great indebtedness of the Institution to Dr. Stanton for the excellence of his Report. [*See* further Communication on page 760.]

Mr. E. H. Saniter said he had studied with the greatest pleasure the exceedingly interesting and valuable Report that had been presented. The Author had given on page 683 the load on the test-piece, but the statement made with regard to it did not quite give the whole of the facts, for the reason that whereas the bearing surface in his (Mr. Saniter's) machine was $\frac{3}{4}$ inch wide, the bearing surface in Dr. Stanton's machine was only $\frac{1}{4}$ inch wide, which meant that the load, instead of being about twice as much, was six times as much on the point of contact. It was possible that the brightness of the worn surface, to which Dr. Stanton had referred, was the result of the difference in pressure. He was not going to suggest it was a better pressure, because he did not know; one pressure might be better for some purposes and another for

(Mr. E. H. Saniter.)

others. After the wearing tests had been carried out on Dr. Stanton's machine, the surface was described as being shiny, whereas after the tests had been carried out on his (Mr. Saniter's) machine with less load there was a distinct mat surface.

With reference to the description of the machine, the question of vibration was all-important, as Dr. Stanton very truly pointed out. It was necessary either to have a machine with a very constant vibration, or one with no vibration at all. The machine on which he made his experiments had been brought to such a stage that there was practically no vibration at all. The whole of the spindle and the chuck were in one piece, and the test-piece was gripped in a hole at the end of the spindle simply by six set-screws with lock-nuts, by means of which centring could be done very accurately; the load was applied by a lever from above. If a key was laid on the top of that lever when the machine was running at 4,000 revolutions, it would not move.

It would be noticed in Table I (page 684) that No. 6, which had a Brinell hardness number of only 420, had given less wear than the one above, No. 5, which had a Brinell hardness number of 453. That was exactly the same class of result as he obtained in his experiments. He had also found, as Dr. Stanton had done, the wonderful wearing properties of manganese steel; both Dr. Stanton and Sir Robert Hadfield had referred to the hardening of the surface that took place, which was no doubt an important factor in the wear.

Dr. Stanton had referred to the increased hardness under the Shore scleroscope after the wearing test, but he further remarked that the increased hardness did not account sufficiently for the reduced wear. He (Mr. Saniter) desired to suggest that possibly the hardness even by the scleroscope was not the true hardness. The film might be so thin that even the scleroscope penetrated to the soft backing, and probably the real film on the surface was much harder than shown by the scleroscope. It had been a great pleasure to himself and also to Dr. Baker, who carried out the work in connexion with his former Report, to notice the way in which their results had been confirmed, and also to hear Dr. Stanton's

opinion that his machine was a valuable one for ascertaining wear. The value of such a confirmation added very greatly to the results given in that Report.

With reference to the other machine which Dr. Stanton had made for testing sliding friction, it was interesting to note that the surfaces were not hardened, and also that there was just as great or greater discrepancy between the ordinary Brinell or Shore tests and the results of wear produced by this machine. All that pointed to the fact that up to date the only way of ascertaining the wearing properties of a steel was by some method of wear testing.

It had occurred to him, in view of the additional knowledge that had been obtained through the issue of the present Report, that it might be possible to define the properties which were necessary to resist wear in the following categories. First of all, he would put the resistance to distortion as illustrated by the Brinell test; secondly, the hardness produced by distortion as illustrated by the manganese steels; and, thirdly, probably the toughness as shown by tests such as the Charpy shock test. He thought that a combination of those tests might be found to give some indication relative to actual wear tests or actual service. For instance, if a piece of steel were tested first of all with the Shore scleroscope and also with the Brinell test, and a further scleroscope test were taken in the Brinell test depression, figures would be obtained which might be an indication of the hardening up properties under distortion. If that were supplemented by a shock test to ascertain the real toughness of material, data would probably be obtained that would give very useful indications. He desired to suggest that, if it were possible, the results of shock tests might be added to the Report in connexion with the other tests on the specimens which had been dealt with.

Mr. S. A. Main said the point which had been raised with regard to the measuring of the hardness number of steel was a very real difficulty experienced by all those in the steel trade. The difficulty was that the Brinell test, which was so much used over

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the ordinary ranges of hardness, broke down in the deformation of the ball, and the Shore scleroscope test also broke down there in the same manner; at any rate, the readings were very variable. It seemed to him that the scratch test had not been sufficiently developed, and that it could be developed to deal with that kind of work. That method had not been used very much up to the present time, principally, he believed, because the indentation and other methods had been so much more convenient, but as those methods failed for the measuring of the hardness of hardened steel, he thought the scratch method should be further considered. In making that suggestion he realized that it was introducing another method of test and another scale of hardness; in other words, they were going over the same ground as they had been going over for years in connexion with temperature scales since the thermometer was invented, namely, the difference between a Fahrenheit and Centigrade scale. The difference, however, existed that they knew with Fahrenheit and Centigrade scales how to change one into the other, and he believed that was not at all possible with the different scales of hardness that were in existence at the present time.

It seemed to the speaker that the question of measuring hardness, and giving a rational figure for it, that is, so as to be able to say that one piece of steel was twice as hard as another, would never be mastered until the real reason for hardness had been discovered. That had been a very difficult problem, and still remained so, which metallurgists, as distinct from engineers, had spent a good deal of time in endeavouring to solve.

Mr. G. F. Barratt said that in the manufacture of ball- and roller-bearings the hardness of the surface of the race was of very great importance, and a method of testing had been evolved by means of which many thousands of pieces a day were tested. It consisted of a rod of carbon-steel hardened and ground off exactly at right angles, the sharp edge thus formed being used as a scraper, and it was extraordinary what a very small pressure was necessary to detect the slightest hardness either due to quenching or to inequalities in the steel. The test was not quantitative; it only

gave soft, tacky, and extreme hardness, but it did that in a reliable way, and he thought it might be worth while for Dr. Stanton to try some such arrangement, and to measure the amount of force that was required with a given pressure to draw the scraper over the work. He had some specimens of rings with him, and the members would be able to see how very delicate such a test was. He also had a roller race with soft patches on it, which had been running with a load of about 6 tons. It showed the blistered appearance of the soft surface where the rollers had run over it.

The only other point he desired to mention was whether the ball in the Brinell machine could not be standardized in some way or other. As far as he was aware, to a great extent ordinary commercial 10 mm. steel balls were used, but no doubt a nickel-chrome steel which could be more or less standardized might be used for the purpose, and in that manner possibly better results would be obtained.

Mr. A. P. Trotter said that he joined in the discussion with great reluctance, because he was not now a professional mechanical engineer; but for the last fifteen months he had been making gauges, and his attention was called to the desirability of testing fairly hard steel for those gauges. In consequence of two observations which had been made in the course of the discussion, he wished to make a suggestion, the first with reference to the hardness of minerals and the second with reference to the desirability of returning to a scratch test.

When his attention was called to the desirability of measuring the hardness of the surface of a small gauge, it occurred to him that a modification of the scratch test might be used. Many of the members were acquainted with the scale of hardness of minerals given in text-books, and many of them had no doubt drilled holes in glass by means of a copper rod with emery. A piece of drill steel, not necessarily of a very definite hardness, with a flat end, say $\frac{2}{100}$ or $\frac{3}{100}$ inch in diameter, might be used. Probably a softer steel would be better than a hard one. Then some substance, which he was not prepared to name, but which he suggested might

(Mr. A. P. Trotter.)

be looked for, might be taken—not necessarily carborundum, probably something softer than that. He then suggested that, putting in a substance as a powder, with or without water, under definite pressure, a small flat-ended cylinder running at given speed, would or would not after a given time produce a perceptible depression in the surface. If the material was too soft, none would be obtained; if it was hard enough, some would be produced, and possibly by selection of material practical results would be obtained.

Another method would be to take a fairly definite abrading material in the same way that a hole was drilled through glass by means of a copper wire and emery, and by applying pressure at a certain speed he thought it might be possible to find some measure —which unfortunately would be a new measure, and would have to be co-ordinated with old measures—of the hardness of hard steel.

The PRESIDENT said it was not his original intention to speak on the Report, but he had a very old interest in the subject of the testing of hardness. Nothing had been said in the course of the discussion with regard to the extreme ingenuity of the device by means of which Dr. Stanton had produced a uniform sliding between the two surfaces by the use of the Oldham coupling between the ring and the piece tested. That machine was, he thought, of quite remarkable ingenuity. In the next place, he thought there ought to be a definite relation between the Brinell hardness number and the scleroscope number. They were both indentation tests, and if that relation did not exist, it rather seemed to indicate that there must be something in the machines or in the reduction of the results which accounted for the difference. In the Brinell tests there were certain small sources of error which were not allowed for in ordinary tests. There was the elastic flattening of the ball and also the raising of the ridge round the ball due to the flow of the metal in producing the indentation. Under the scleroscope test it seemed to him there must be something of a difficulty in getting anything like a uniform scale, seeing that there was quite an arbitrary form of diamond point to make the indentation.

Strictly, there ought to be a definite relation between the Brinell hardness number and the scleroscope number.

Sir Robert Hadfield had suggested that there was still a great difficulty in testing very hard steels for hardness. It was easy to see that, using the Brinell test, the errors in the test increased in that case, because it was necessary either to depend on a very small indentation or to use a very heavy weight, in which case the indenting ball was deformed. He had to a certain extent a preference for indentation by a cone, and for measuring the depth of the indentation. The same result was obtained whether the depth of the indentation was measured or its diameter, but he had a speculative preference rather than a practical one for a cone and measuring the depth of the indentation. The suggestion he made was merely a vague one; but it seemed to him it might be possible by the use of a cone or a slightly truncated cone—it would probably have to be truncated to avoid the point being injured—and measuring the depth of the indentation, using an optical magnifying arrangement which would give very much greater delicacy than could be obtained in measuring the diameter of the Brinell indentation. The test for hard steels failed for one thing in want of delicacy, and he merely threw it out as a suggestion that it might be possible by optical magnification of the movement of the cone to get a very much greater delicacy of indication.

Dr. T. E. Stanton, in reply, said he desired to add his testimony to that of Sir Robert Hadfield in regard to the very great help and encouragement which all who had been working on the subject had derived from the President. The President had written a great deal on the question and had taken much interest in the work, for which they were all very much indebted to him. He was glad indeed that Mr. Saniter had been able to be present and join in the discussion. Mr. Saniter had offered to show him his machine in the following week at Sheffield. The rolling abrasion test was an extremely difficult one, and he thought considerable credit was due to Mr. Saniter for the able manner in which he had perfected his arrangement. Personally, he thought it was quite the best

(Dr. T. E. Stanton.)

method in existence of determining the resistance to rolling abrasion.

Both the President and Sir Robert Hadfield had referred to the relation between the Brinell hardness number and the scleroscope number. He thought that Fig. 7 (page 692) showed fairly well that, at any rate for the softer steels, the relation was very definite indeed. He was sure Mr. Batson would agree with him in the statement that the scleroscope was not an instrument to be put into the hands of a beginner; it required very delicate handling indeed to get consistent results with it. He would not like to conclude his remarks without putting on record his great indebtedness and, he believed, the indebtedness of the Committee also, to his colleague Mr. Batson, who had carried out all the tests. It was really due to Mr. Batson that such a measure of success had been obtained, and he possessed the most valuable characteristic of a worker in engineering research in that he was never discouraged. If they had put down particulars of all the failures they had met with in connexion with this particular research, it would not probably be very interesting to the members, but it was the overcoming of the failures that constituted the real definiteness of the work.

Discussion in Sheffield, 1*st Dec.* 1916.

Mr. J. Rossiter Hoyle (Vice-President), who presided over a large attendance, said the subject of the Report was one of the greatest interest and importance to members and others engaged in Sheffield industries. The definition of the hardness of steel had engaged their attention for a long time, and the Research Committee had dealt with it, he need scarcely say, in a most masterly manner. He was sorry Sir Robert Hadfield could not be

present on that occasion; he had taken the keenest interest in the work of the Research Committee, and as the members would see, had contributed to its investigations and conclusions. Professor Arnold was also unable to be present, as he could not get back from London in time to attend that Meeting. The Chairman then called upon Dr. Stanton to present the Report, and he gave a short summary of the work dealt with in the Report.

Mr. E. H. Saniter, in opening the discussion, said he would first of all like to acknowledge the value of the work the Institution was doing in appointing various Research Committees. That dealt with by Dr. Stanton was the latest, but it had many valuable predecessors. The Report of this particular Committee on Hardness Tests had been of the greatest interest to him. Dr. Stanton had referred very largely to the report made by the speaker before the International Association on the Testing of Materials at New York, and he had confirmed the results which were given there. It added very greatly to the value of that Report and also to the value of Dr. Stanton's Report that they gave practically identical conclusions. This agreement established the value of the method. This Report also showed that variations in the manner of carrying out the tests did not invalidate the results obtained. In saying that, of course, he meant any difference in carrying out the test, such as those mentioned on page 683, where the load given as worked with by Dr. Stanton was 410 lb. at the point of contact. The load worked with by the speaker on his machine was 205 lb., but, in addition to that, Dr. Stanton had only a bearing surface of one quarter of an inch wide, while in the speaker's there was a bearing surface of three-quarters, which made the difference in the load at the point of contact six times as much. In spite of that great difference in the application of the test, the results obtained were confirmatory of each other. The question of vibration was most important in carrying out tests of that description. They must either have a machine with a very constant vibration or a machine with no vibration at all.

In Table 1 (page 684) it would be noticed that there was a

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variability in the results as obtained by Dr. Stanton similar to those formerly obtained by the speaker, the specimen tempered at 500° C. giving a greater wear than that tempered at 600° C., although the Brinell number was in the reverse direction. As Dr. Stanton said, the majority of the results on plain carbon steel came out pretty well along the line of the Brinell, but there was one test which absolutely disagreed. He did not know how many times they checked that test to make sure it was not an aberration of the machine. The point brought out by Dr. Stanton in connecting up with wear the formation of a surface hardness by distortion was very interesting, and made it quite plain why manganese steel was such good wearing steel. Dr. Stanton (page 686) referred to this hardening up action as indicated by the Shore scleroscope as being insufficient to explain entirely the large increase in wear, but he (Mr. Saniter) would suggest that the Shore scleroscope did not give the true hardness, but found its way through the hard film to the soft backing. He would like to say on behalf of Dr. Baker and himself—Dr. Baker really carried out the tests—that it had been very gratifying to have such thorough confirmation of their results.

Referring to Dr. Stanton's own machine, he thought it a very ingenious one. The results were exceedingly interesting. The fact that in sliding wear of that description one did not harden the surface, the same as in rolling friction, was most extraordinary and unexpected to his mind. With reference again to the question of endeavouring to get some correlation between the ordinary hardness tests and wear tests, he would suggest that the following might possibly be worked out: the resistance due to distortion as taken by the Brinell test; the surface hardness caused by distortion by the Shore scleroscope test in the Brinell impression; and the toughness or resistance to shock as indicated by the Charpy shock testing-machine. He (Mr. Saniter) could not help thinking that toughness had much relation to the wearing properties of steel, in addition to hardness. He did not know whether Dr. Stanton was wanting more work, or whether he was able to do anything in the matter, but he thought that if he could add a shock test to the

series of tests he had already made, it would be a valuable addition to the Report.

Dr. W. H. Hatfield (Brown-Firth Research Laboratory) said that all who were interested in the question of hardness testing had looked forward with the greatest interest to the publication of the Report of the Hardness Tests Research Committee. He and those associated with him were greatly interested in the different methods of testing hardness, and some time ago they came to the conclusion that the present means were inadequate. On receipt of this Report, they had naturally studied its contents with the greatest care, and he wished to take that opportunity of recording his appreciation of the work that had been done. The term "hardness" had a definite meaning to the lay mind, but to the expert engineer and metallurgist its meaning was extremely indefinite, and it was to be regretted that attempts had been and were being made to include such a wide range of properties under that specific heading. As a matter of fact, what they really wished to determine was not "hardness" in many cases, where they were actually using so-called "hardness" testing machines. The Report made a special point of emphasizing this aspect of the matter, and in that connexion he would like to refer particularly to the memorandum communicated by Sir Robert Hadfield. The statement was an extremely valuable one, and put the case well. This particular Appendix would be appreciated fully by anyone who was intimately concerned with the hardness properties of steels, and their feeling, at the Brown-Firth Research Laboratory, was that they heartily agreed with every word contained in that contribution.

Turning now to the Report itself, he found on page 705 it was stated that "It will be found that hardness as determined by the methods described above and resistance to abrasion or wear are not in any exact relation." It could hardly be expected that they would be. People who used the Brinell, Shore, and similar tests decided long ago, he thought, that there was no relation. Different forms of hardness determinations were utilized for determining the best condition of various steels called upon for unlike service, and

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as an instance he did not think he could take a better illustration than ball-bearings and the action of driving wheels upon the rails. If they considered a ball running in a race, a state of conditions was demanded which included a minimum of friction under a maximum load, and it would appear that the requisite hardness in this case was best measured by a hardness test which had its basis in the elastic properties of the material. With regard to railway tyres and rails, they were under the impression that Mr. Saniter's machine (one of those dealt with) was devised with a special purpose in view, that is, that of determining the effective hardness for rails. He would like Dr. Stanton to correct him if that was not so. It might be presumed that there was a condition below the maximum hardness for driving tyres and rails, at which the tangential force capable of development would attain its maximum (in the case of the ball-bearings the tangential force was of a much lower order), and therefore, in studying this aspect of the matter, the "hardness" to be desired was the maximum of that quality which would give the longest life of rail with the capacity for developing the high tangential force, which apparently had very little to do with the ordinary conceptions of hardness. He thought it was obvious that Mr. Saniter introduced in his machine a means of bringing that action into play somewhat.

Turning to page 684, they found a Table containing an extremely valuable set of data, which he thought would be considerably enhanced in value by the addition of the results obtained on the same materials under tensile and other forms of test. This was particularly desirable in view of the necessity, so well brought out in the Report, of correlating all other possible values with those obtained under the different forms of hardness test. If the results of tensile, impact, and other tests were available, he thought it would be extremely useful to have them. With regard to the results in this Table, he could not pass them without saying that he thought the value of 720 hardness number obtained for Nos. 1 and 2 seemed rather high, particularly when it was appreciated that, when such Brinell hardness numbers were obtained, the machine became unreliable. Anyone with experience of the Brinell machine

would appreciate that, even when they got over 650 hardness number, they were in danger of flattening the ball; and after all the efficiency of the machine was largely dependent upon the properties of the ball itself. He noted that in a later Table in the Report the Committee made a special note as to the unreliability of the figures obtained when the hardness was so high.

He was rather at a loss (along with Mr. Saniter) to appreciate the reasons actuating the investigators in using the Brinell test and the Shore test for measuring surface hardness. Since they were up against this question of measuring surface hardness, he thought the Institution would have much appreciated it if the Committee had devised some means for adequately determining the hardness in such thin layers of material. He knew it was very difficult to undertake, but it was one for the solution of which they were all waiting. Speaking of the Shore test, he found that Dr. Unwin, on page 705, gave a hardness number of 100 for a *medium* hard condition, and from his subsequent remark this would be taken to correspond to a Brinell hardness number of 600. It might interest the Committee to know that, in their Laboratory, they had carefully examined a standard block of material supplied with the Shore scleroscope. The Shore Company stated the hardness of the block to be 93 to 95. On checking the block, they found that the hardness was exactly as stated, but when they checked the hardness by the Brinell machine they obtained figures of 683 and 652, which, in their opinion, were almost as hard as could adequately, quantitatively, be measured at the present time. They were inclined to consider such hardness numbers as being rather more than *medium* hard, and yet it would be clear that the figure of 100, given by Dr. Unwin, was not attained. They would very much appreciate some information as to the experience of other investigators with the Shore and the Brinell scleroscopes on these points.

Turning to page 689, he found it suggested that "by the relative sliding small particles are bodily detached without permanently distorting the surrounding particles." It seemed that there they had a very vital statement. Was he to understand the

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Committee to indicate that, under conditions where the elastic limit and the maximum stress in a material did not synchronize, that is, where there was a diagram of plastic work under tensile test—rupture would take place immediately the elastic limit was attained; or otherwise, that under those conditions the work was not actually done upon the particle which was broken? He could hardly conceive, himself, that one particle could be broken from another without some deformation taking place. He might have misread the meaning of the Committee, and he should like to hear what Dr. Stanton had to say upon the point.

Turning to Dr. Tutton's definition (page 712), the speaker referred to the statement that "Moreover, high specific gravity (density) is generally accompanied by great hardness." He did not think that was a statement which even the general facts would permit. The diamond, with a maximum hardness number of 10, had a specific gravity of 3·5, whilst barytes, with a hardness number of 2·5 to 3·5, had a specific gravity of 4·5. If they considered substances like chalk and limestone, and compared them with granite, they found the specific gravities were very similar. Turning to steel, Dr. Unwin stated the hardness of soft iron, on Moh's scale, to be 4·5, and that of a hardened steel 6·5, but the specific gravities of hardened steel and soft iron were practically identical—in fact, hardened steel had a less specific gravity than soft steel. Bearing on that, Mr. McCance, in a Paper to the Iron and Steel Institute about two years ago, gave the actual data. He found that 1·18 per cent. carbon steel, quenched from 840–845° C., had a hardness of 713 Brinell with a specific gravity of 7·73, whilst annealed, its hardness number was 176 and its specific gravity 7·818. Again, Dr. Tutton spoke of "the points of the space-lattice being the closer together the denser the substance," etc. Here, one might remind him that ordinary glass, which had a specific gravity of about 3 to 3·5, was so hard that the hardest steel would only just scratch it.

Discussing the Report now from a general standpoint, he might say that they had carefully studied the work of the Committee in the light of their daily experience at the Brown-Firth Research

Laboratory. Some of the work there, as would be appreciated, was of such a nature as to make the whole question of supreme importance, and they proposed to make the following additional observations for the consideration of the Committee :—

With regard to the relationship between hardness and resistance to wear :—

(*a*) *Pure Sliding Abrasion* (*lubricated or not lubricated*).—They would suggest that the resistance to wear for a given material would depend on the pressure and on the speed. Very probably it would be found that as the pressure increased, the wear would increase fairly uniformly up to a certain point (a kind of "critical point"), beyond which the wear would increase more rapidly. The position of this point would apparently be related in some way to the ultimate strength of the material, and would be different with different materials.* Hence the fixing of "standard conditions of testing" could not be satisfactory, since the pressure and speed were bound to be just favourable values for some materials and unfavourable for others. A complete report of the resistance to wear for any material should, they suggested, include tests for a range of speeds and a range of pressures. He knew this was suggesting much work, but the Committee, naturally, had undertaken an extremely wide subject, and he thought Dr. Stanton would agree that their present preliminary Report dealt with only a limited aspect of the matter. A study of the form of the "law of variation" would be useful, including observations on the "critical points," if any.

(*b*) *Rolling Abrasion*.—Here again everything depended upon the standard conditions adopted. They would suggest that the variable quantities were pressure, curvature of rolling surfaces, speed, lubrications, "slip" and tangential or adhesive force, and vibration. Altering the curvature of the surfaces was obviously equivalent to altering area in contact, hence, if the pressure was varied accordingly, equivalent conditions of wear should be obtained.

* *Cp.* Nusbaumer, International Society for Testing Materials, 1909.

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In such tests as these, they thought it would be very useful if the temperature conditions were recorded, also the energy absorbed in overcoming friction, and the plastic flow of material at the surface. The influence of vibration, which had been so ably pointed out by Mr. Saniter, seemed to them to be a subject to which attention was particularly desirable, since it was essentially one of the conditions of practical working.

Microstructures.—The Report in its present form made no reference to the microstructures of the material. They thought it would be useful and probably instructive if the results of a microscopic examination of the materials in their different conditions were given. They might have two materials of a like hardness, one of which was homogeneous while the other consisted of two constituents, one hard and one soft, and one could hardly expect two such unlike materials of the same hardness to behave similarly under wear.

In conclusion, he would like to record the appreciation of the firms with which he was associated of the excellent work done by the Committee, and also to say, on behalf of himself and the senior members of his staff, Messrs. Bolsover and Stanfield, that it had given them real pleasure to study the Report.

Professor W. Ripper said he had been greatly interested in reading the excellent Report on Hardness, and they appreciated highly the results that were obtained. It was a matter of particular interest to Sheffield. The whole gist of the Report was the getting away from the more elementary tests for hardness on to tests for resistance to wear. There was no doubt that the engineer desired more information on that matter. In these days of high speeds in all types of machinery it was of importance that the journals of machines, engines, and dynamos should be made of material which should stand, up to the great speed and exacting conditions to which they were subjected. One of the most elementary points in machine and engine designing was to have a bearing whose projected area should secure that the pressure applied to that journal should not exceed a specified amount,

otherwise the effect was to squeeze out the lubricant and allow actual contact to take place between the bearing and the journal. The engineer assumed that actual contact did not take place. Sheffield particularly knew what the effect of that idea on the engineer's mind had been on the designing of crank-shafts and crank-shaft journals. In the early days, when high speeds and large internal-combustion engines came in, an enormous number of fractures of crank-shafts was experienced, and the designers began increasing dimensions, these dimensions being determined by the pressures permissible on the projected area of the bearing. To the metallurgist, that aspect of the question might be of interest.

The subject of hardness had recently come under his notice in connexion with experiments he had recently been carrying out on testing carbon tool-steels, in the course of which arose the question of the relation of the hardness of the material which was being cut as measured by the durability of the lathe turning-tool and the relation of the work done by the turning-tool to the Brinell hardness. In using a portion of a very large shaft as a test-piece for making tool tests with, they found that the shaft was different in hardness from end to end as measured by the Brinell test. They divided the test-piece into a number of zones for differences of hardness, and they took care that every tool had its chance in every one of those zones. In plotting the results of the amount of material turned off against the Brinell hardness, it occurred to them to determine whether there was some relation between the work turned off and the Brinell hardness, because after all the ordinary lathe turning-tool working on a bar and cutting its surface was a kind of magnified abrasion test, and he thought it would be of interest to members to know just what the result of that small investigation was which was to determine whether or not there was any relation between the Brinell hardness test and the hardness as measured by the turning test. He might add, they had a very definite way of determining the breaking-down point of the tool, and therefore the results obtained were reliable and capable of use for such a purpose. Curves were plotted, and the abscissæ showed the

(Professor W. Ripper.)

Brinell hardness scale and the ordinates the weight of metal removed from the bar. If the ratio between the Brinell hardness of the material, and the material turned off, was a simple one, and if the ratios were exactly equal, then they would get a line at 45°; in other words, the tangent of that angle would be one. Very many of the tools tested gave results which when plotted almost coincided with that dotted line, but the majority of the tests did not so coincide, but were at some other angle. There were 53 different curves drawn, and the average of all those lines showed a relation between the weight of material turned off and the Brinell hardness test, varying between 1 : 1 and 1 : 1·9. Each tool had its own particular curve, all coming more or less within a certain limited range, but these experiments went to show that there was no quite regular relation between the hardness as determined by a tool cutting the surface and the Brinell hardness test, although in the case of many tools the relation between the two scales was very nearly equal to 1 : 1.

Dr. F. C. Thompson (University of Sheffield) said he had been asked by Professor Arnold to say a word or two on a point which was almost the converse of that dealt with by Professor Ripper. The latter gentleman had dealt with the matter from the point of view of the Brinell hardness of the material turned away. Professor Arnold had asked him to give a short account of some of his (Professor Arnold's) work, looking at the question from the opposite point of view—that of the hardness of the tool which was going to turn away the shaft. In a recent note* he was able to show, perfectly definitely, that so far as the turning tool was concerned there was absolutely no relationship whatever between its Brinell or scleroscopic hardness and its life in the lathe. Taking, for example, a turning tool of pure 1·25 per cent. carbon-steel with a Brinell hardness approaching 700, under the conditions under which Professor Arnold has made his tests, the life of the tool would be about two seconds. On the other hand, the mean of a

* J. O. Arnold, Journal, Iron and Steel Inst., 1916, i. p. 102.

very large number of tests made with high-speed steels of varying compositions—the mean hardness of which was only 600 on Brinell's scale—showed a life of somewhere about 18 minutes, that is, more than 500 times the life of the harder tool. The scleroscope results, in exactly the same way, showed no relationship whatever between the efficiency of the turning tool and its hardness number. This, of course, was more or less what would be expected, looking at the matter from the microscopic point of view. The life of a tool in a lathe was going to depend much more on the thermal stability of the hardenite, which was the primary constituent, than on the hardness of the tool itself. Since the special steels which were used for high-speed tools had a breaking-down point of a very much higher temperature than that of the plain carbon steels—in certain cases a breaking-down point at an actual red heat—it was at once obvious that no comparison could be expected between the work that such a tool would do and that which would be done by an ordinary carbon-steel, despite the greater hardness of the latter. Dr. Arnold had further shown that the remarkable increase in the thermal stability of a high-speed tool due to the introduction of vanadium had resulted in no appreciable change of hardness. At the present time this point was perhaps worthy of emphasis, as the results of other investigations which had been put forward from a more academic standpoint suggested more or less that there was a distinct relationship between the Brinell hardness of a tool and its efficiency in the lathe—an erroneous and pernicious belief.

The Report was so full of material that it was impossible to deal with more than a very small part of it in a discussion. He supposed the dominant feeling of all present would be the desire that, like the Alloys Research Reports, the Reports of this Committee should become perennial. It was always easy to plan work for other people to carry out, but he supposed most people would agree with Dr. Hatfield in this respect, that they certainly hoped for more. Some work that he (Dr. Thompson) had done recently* had perhaps some bearing on the question of the correlation

* F. C. Thompson, Journal, Iron and Steel Inst., 1916, i. p. 155.

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of the different types of hardness tests. Looking at the matter both from a theoretical point of view, and from a consideration of the mechanical properties and microscopic structures of a large number of steels, he had come to the conclusion, which, though by no means definitely proved at the present time, yet offered considerable probability that confirmation would be forthcoming. As perhaps all present there knew, an ordinary metal consisted of discrete crystalline grains which met along the crystal boundaries, about which a considerable amount of discussion had taken place in recent years. At first sight those boundaries would, of course, be expected to be regions of considerable weakness, but as a matter of fact the exact converse of that was well known to be true. The point which he wished to emphasize was this: it appeared to him that the factors which determined the elastic limit, and the factors which determined the tensile strength, or the Brinell hardness, were dependent on two entirely different structural details. The elastic limit appeared to depend to a very large extent indeed upon the actual crystal boundaries, whereas the Brinell hardness or the maximum stress depended to a very much greater extent on the crystalline material of the grains. To give a couple of examples which emphasized this point: he obtained specimens of a very pure crucible melted iron, containing 0·05 per cent. of carbon. One specimen was in a finely-grained, and the other in a coarsely-grained, condition, otherwise they were, practically speaking, identical. In the coarsely-grained state, the true elastic limit was 9·6 tons per square inch, whereas in the fine state it was 12 tons per square inch, an increase of about 25 per cent. The corresponding increase in the maximum stress was only about 3 per cent. from 21·1 to 21·8 tons per square inch. He examined another steel containing 0·26 per cent. of carbon, and found that the elastic limit could be raised simply by refining the grain size, by no less than 275 per cent., while the maximum stress itself was increased by only 12 per cent. These figures certainly, to him, seemed to indicate that the maximum stress and the elastic limit were, to a very large extent at any rate, governed by different factors. Now since under any circumstances the Shore scleroscope must give a

measure largely of the elastic properties, dependent on the crystal boundaries, whereas the Brinell hardness more directly gave something corresponding to the maximum stress, and so was related to the crystals themselves, it was not to be expected that an absolute correspondence between the two should be shown; in fact, personally he had always felt distinctly surprised that there was so near a relationship as had been found to be the case.

One question which he would have been pleased to see in the Report was a discussion of the relationship between the Brinell hardness and the maximum stress. When all was said and done, the most common method of measuring the hardness of a metal was to determine its tensile strength. There were theoretical reasons for believing, and a certain amount of experimental evidence was available in confirmation, that Brinell hardness and tensile strength were related by a straight-line curve. Further work on that point was, however, desirable, and it would be a good thing if the Committee could see their way to deal with this aspect of the subject.

With regard to Fig. 7 (page 692), it might be worth while mentioning that the high-speed steels used by Professor Arnold for his tests had a Brinell hardness of about 600, while the mean scleroscope hardness was about 81.* These figures were the mean of a large number of tests, and would appear to indicate that the curve bent down for the harder materials rather more abruptly than was shown in the figure.

Dr. Hatfield had already referred to the very interesting Appendix by Dr. Tutton, and he personally was in complete agreement with him (Dr. Hatfield) that the statement that density and hardness were correlated needed a considerable amount of proof. Among the metals, the two cases of lead and platinum were obvious exceptions. It had been shown, however, that the hardness was more nearly related to the atomic volumes. Professor Turner, in 1909, correlated a large number of atomic volumes of the common metals with the corresponding hardness, and found

* J. O. Arnold, *loc. cit.*

(Dr. F. C. Thompson.)

that, in a very large number of cases, as the atomic volume had increased so the hardness had decreased. That was, he thought, what they would expect. If they considered a box into which they were going to put hard spheres inter-connected together by elastic linkages, then if the volume occupied by each sphere were decreased—that was to say, if they put more spheres into the box—then obviously the difficulty of introducing further spheres was going to be increased. If in one case they had double the number of spheres in the box that they had in another—that is, if the "atomic volume" were halved—then it was perfectly reasonable to assume that it was going to be much more difficult in that case to introduce other spheres than it would be if they had less—in other words, the "hardness" would be increased.

Touching Sir Robert Hadfield's admirable summary of his views on hardness, he said Sir Robert had defined hardness as "resistance to deformation." At first sight, that definition was amply sufficient. Since, however, from the engineer's point of view, deformation was often—in fact, generally—elastic, it must be remembered that such a definition hardly covered the conditions required for a definition of purely elastic hardness. The resistance of a steel or any metal to deformation, so long as that deformation was purely elastic, was measured by Young's modulus, and since Young's modulus was, practically speaking, the same for all steels, from the softest to the hardest, the elastic hardness from that point of view was unchanged, although the Brinell hardness had increased enormously.

Mr. G. W. Burley said that those who had read the Report would much appreciate the work which had been done by Dr. Stanton and his colleague at the National Physical Laboratory. He was pleased to find that mention was made of the vagueness—one might say the nebulousness—of the ordinary idea of hardness. Of course, to the ordinary man the term might have a definite, though restricted, meaning; he generally associated it with some sort of scratching—a substance which was harder than another being able to scratch the second. But the engineer, and particularly the scientist, must have some more definite and applicable idea of what was meant by

hardness. It seemed to him, as apparently it seemed to Sir Robert Hadfield, that hardness could not be defined in any simple way. As had been pointed out in the Report, tests which had been applied for the purpose of determining hardness could be divided into two classes—those of indentation and those of abrasion. He did not think, however, that abrasion tests could be carried out without involving some sort of indentation, for it seemed to him that before they could get abrasion they must have some sort of indentation, though this indentation might not be of exactly the same type as that produced by mere compression. To take the case of an ordinary lathe-tool: they must force it into the work—in other words, cause it to indent the work, before they could cause it to cut; and after all, the cutting action of a lathe-tool, or that of the teeth of a milling-cutter or the lips of a twist-drill, was only an abrasive action on a very large scale. In such a case, it was true, they were not dealing with microscopic quantities, although it seemed to him that if they wanted to get to the root of the matter, and find out exactly how a tool did cut, they must deal with it from the microscopic point of view. They must not regard the lathe-tool, for instance, as merely removing a long shaving of steel. It was something more than that. As a matter of fact, it was hardly a continuous shaving, as engineers of course knew.

He was interested in this subject more from the point of view of the cutting-tool than anything else at the present time, and it seemed to him that this sliding abrasion test did not give them information which would lead them to determine the superiority of one steel over another for cutting purposes. This was indicated by the Tables of results. For example, in Table 2 (page 697), test No. 21 related to a self-hardening steel, air hardened, which gave a resistance to sliding abrasion of 500. But in the case of test No. 31, a gauge-steel, hardened, which was practically a plain carbon-steel (he admitted that it was rather low in carbon, though this probably made the contrast all the more pronounced), they had a resistance to sliding abrasion of 1,000. From that, it might be assumed that the plain carbon gauge-steel was twice as good as the self-hardening steel in the form of a cutting-tool, but of course they

(Mr. G. W. Burley.)

all knew that that was not so. An explanation of this might be that in these tests the question of temperature had been ignored. In a cutting-tool, especially one made of high-speed steel, the question of temperature was of some importance, and probably if the tests were made at higher temperatures the results would be different, and would be more compatible with those obtained in ordinary practice with cutting-tools generally.

In regard to the diagram which Professor Ripper had described, he might mention that there the range of hardness, as measured on the Brinell scale, was comparatively small. He did not think that those curves showed that the Brinell hardness numeral of a metal generally determined its cutting or machining properties. He was not now referring to the tool—he was assuming constant, or standard tools—but was thinking of the material which was to be cut. Of course, in the machine shop, the workability, or the cutting quality, of the metal was of some importance. The diagram showed that between the two limits of about 100 and 150 there was a fairly definite relation between the weight of metal removed and the hardness number, but they did not suggest that that relationship held beyond those two limits. As a matter of fact, they were only concerned, in that particular case, about the work done by the tools on the different parts of the particular bar, which had a Brinell hardness number ranging from 100 to 150, but it was found that the relationship between the weight of metal removed by the tools under standard test conditions (not, of course, including the physical and chemical characteristics of the test-bar) and the Brinell hardness number of the test-bar, as it varied longitudinally and radially, was in each one of 53 cases represented by a curve which was practically a straight line within the limits of hardness of the test-bar.

Mr. George Rodger said the only point of view from which he could regard the Report was that of the engineer. He looked through it to see if he could get any help from it in his own business, and was afraid he had not succeeded in getting anything out of it. The one thing that had been established was that the

Brinell test and the scleroscope test seemed to run fairly well together. The whole thing seemed to originate from an inquiry by a firm of engineers as to what hardness they should make their shafts in order to get them to run well and last well. From that very technical and practical question the Committee, for whose names he had the very highest respect, seemed to have gone into a sort of academic and abstract investigation which he was afraid would not be of very much assistance to the people who put the inquiry. The conditions were something like this: every railway engineer ran his rails and his wheel as dry as he could, and every engineer who had a crank-shaft to look after ran it as well lubricated as he could get it. He was a little at a loss to imagine how a dry running test could be of the slightest service to the engineer in keeping a crank-shaft cool. As Professor Ripper had told them, the engineer had to get a film of oil always between the two surfaces, the bearing and the shaft, and when that film failed there was wear and destruction. He (the speaker) did not think it mattered very much whether the shaft was hard or soft, for the undesirable result was reached more or less quickly. The principal thing an engineer had to consider was whether his shaft was strong enough to transmit the power safely. After he had got that condition, he made it as hard as he possibly could with regard to durability in other ways—safety from fracture, cracking, and so on. He thought that the real test of shafts was not what they would do when running dry, but what they would do when running, say, with forced lubrication or the best lubrication that one could give. Much credit was due to the investigators, who had spent so much time on the matter.

Dr. F. Rogers said that, of the many factors which entered into the question of a satisfactory hardness test, they must all admit that the most important had undoubtedly been well recognized in the Report. The rolling velocity, and the relative velocity of the rolling surfaces, that is to say, the slip, were recorded in the Report, and also the total pressure normally of the two rubbing surfaces. He would like to mention other extremely important

(Dr. F. Rogers.)

factors. The first of these was the total tangential pressure between the rubbing surfaces. Besides this, they must also consider one other point, which was really at the root of the explanation of the abrasive action, namely, the local normal pressures, because there was no such thing as a perfect surface contact. Secondly, they must consider the local tangential pressure for the same reason. It was the local tangential pressure which settled the question of the material abraded, or rubbed off.

The known forms of hardness tests—the Brinell and the Shore—dealt entirely with the question of normal pressure. They were practically the same thing, although they might give somewhat different indications. The chief difference was that in one they measured the dimensions of the impression produced, and in the other they measured the work required to produce it. Abrasion was really nothing more or less than approximately tangential indentation, and that was the crux of the difference between the abrasion test and the indentation test. From that it followed, to his mind, that the rolling test, accompanied by a certain amount of slip, was a very important thing. He thought that Dr. Stanton had shown that he had achieved that—he had obtained consistent results in successive periods of running.

He (the speaker) thought that a very practical means of obtaining an abrasion test was the sand-blast, and as a matter of fact very much of the steel made in Sheffield was tested by purchasers' engineers in a sand-blast. The difficulty, from the point of view of an investigator, about sand-blast, was that of standardizing it. Without a standard sand-blast test, one did not want to set it up in the laboratory. Some time ago, he had the idea of making a standard sand-blast test, though of course not with a manufacturing sand-blast apparatus. The result was a little machine, illustrated in Fig. 15 (page 776). In the machine, the specimen was rotated in the mixture of water and an abrasive. It was a very simple test made upon a small sample of the steel or other metal. The specimen was simply weighed before and after the test, thus giving the amount abraded. The members would be interested to know that he had also examined some of the samples

under the microscope after they had gone through this abrasion test. So far, he had only been able to detect the grosser features of the microstructure brought out in that way. Of course, that would be understood, because naturally the abrasives he had used in the test had been in large particles, and what they saw under a high magnification was a series of short scratches or elongated indentations. They would see that this was a type of test which, just like the sand-blast test, was really something in the direction of producing nearly tangential indentation; much of the metal which formerly occupied those indentations was bodily cut out by the energetic contact with the grain of abrasive material.

Dr. T. E. Stanton, in reply to the discussion, said that there was so much in Mr. Saniter's remarks that he could agree with, that there was not very much for him to answer in what that gentleman said. He quite agreed with Mr. Saniter that the scleroscope probably did not give the true hardness of a surface which had been subjected to rolling abrasion. The same matter was also referred to by Dr. Hatfield. The only thing he would like to point out was that it was certainly no good making a Brinell test of a hardened-up surface of the kind they had to deal with, and the best way of doing it seemed to be to make a scleroscope test on it.

Mr. Saniter suggested that they should make impact tests, and compare the results with the resistance to wear. With regard to that, they had a separate research, and one of considerable difficulty, now going on at the Laboratory on notched-bar impact tests, but he thought there would be one troublesome feature about carrying out Mr. Saniter's suggestion. Those materials, which had high resistance to wear, had, as a rule, extremely low resistances in the notched-bar impact test, and he thought that possibly the errors in estimation of their true resistance would tend to vitiate the results. They would, however, look into that a little later.

Dr. Hatfield had referred to Table 1, and suggested that the tensile resistance should be given. He (the speaker) ought to have said that the specimens referred to in that Table were sent by Sir

(Dr. T. E. Stanton.)

Robert Hadfield. He did not think that Sir Robert had any to spare on which they could make tensile tests, but he would speak to Sir Robert again, when he had the opportunity, and, if he had any more specimens, he (the speaker) would be very glad to incorporate the results of the tests in the Report. Sir Robert might have the results already, but he was inclined to think not, because these steels were extremely hard, and he was not sure that they would get a satisfactory tensile test out of them. He ought to say, too, that the Brinell hardness numbers to which Dr. Hatfield referred were furnished to them by Sir Robert Hadfield himself. They checked some of them, and found the results quite in agreement. He was not quite sure what Mr. Batson's experience was with the too high values to which Dr. Hatfield had referred.

Dr. Hatfield, he saw, had saddled the Committee with a statement for which the responsibility rested not with them, but with him (the speaker) personally. This was the statement (page 689) in sliding abrasion that "small particles are bodily detached without permanently distorting the surrounding particles." That was his way of describing an action which could not be precisely defined. He remembered that Dr. Unwin told him that he thought very likely the statement might be objected to, but he would not make any suggestion about it—he said it would improve the discussion. He (Dr. Stanton) was quite willing to take full responsibility with reference to that remark. He thought he must leave Dr. Tutton to reply to the various criticisms of his definition which had been made. They were very much obliged to Dr. Hatfield for the excellent suggestions he had made for future work. They hoped, if they could, to undertake such researches as he had suggested with regard to the dependence of resistance to wear on pressure and speed, and also the other facts which he had mentioned.

He was much interested indeed in Professor Ripper's tests, which were of a kind of which he had not had any experience, and also in the reference which Dr. Thompson made to the hardness of cutting tools and its apparent independence of the value of the Brinell hardness tests. Mr. Burley also called attention to the

fact that probably the tests referred to in the Report would not apply to the case of cutting tools. The whole point of the Report was that they should not do so. The value of the work done was, he thought, simply a testimony that they must set up scale model tests if they wished to make accurate predictions of resistance to wear. It was the case of a ship over again. If one wished to determine the resistance of a ship moving through water, it was necessary to make a scale model test, and to fulfil their similarity conditions exactly. It seemed to him that in these wear tests they had to do the same, that they could not hope to get a test which would give them the resistance of a cutting tool to wear unless they set up a scale model of the actual thing itself and determined it under working conditions. He thought that statement would also apply to the remark of Mr. Rodger, who said that the results were quite worthless for lubricated surfaces. Of course, the investigators quite recognized that. If they wanted to know the resistance of lubricated surfaces to wear, they had to get a lubricated surface and try it.

He was very pleased to renew acquaintance with his old colleague, Dr. Rogers, who was at the National Physical Laboratory some years ago. He knew Dr. Rogers as a very keen research worker, and was glad to have his remarks on the Report. He thought that Dr. Rogers' explanation of the general effect of the difference between the Brinell test and the sliding abrasion test was probably a correct one. In the Brinell test they got a resultant normal pressure, and in the sliding abrasion the effect was approximately tangential, and they could not possibly hope that the two tests would give the same results.

The Chairman, in calling for a vote of thanks to Dr. Stanton for visiting Sheffield and giving them the benefit of the valuable experience of the Committee, said that the work was of very great value.

The thanks were heartily accorded.

Dr. Stanton, in reply, expressed his pleasure at the large attendance, and said the Meeting was most impressive.

The Chairman said the attendance was one which did Sheffield very great credit. He was very glad to see such a large number there, and he would tell the Council how much the Meeting had been appreciated.

Communications.

Sir Robert A. Hadfield (Member of Council) wrote, in continuation of his remarks at the Meeting, that from Wahlberg and Brinell's Papers to the Iron and Steel Institute in 1901, he (Sir Robert) had extracted the following, which appeared to be still of considerable value to those interested in the subject. These Papers really constituted the beginning of the important line of hardness investigations, and in them was much useful information as to the results of ball hardness tests:—

As regards the influence on hardening results of different hardening temperatures, it is stated that the object and purpose of hardening is not only to fix to the greatest possible extent, by means of sudden quenching, the carbon contained in the material in the state of hardening carbon, but also to obtain a steel the structure of which will be as finely crystalline as possible or amorphous. It is only when both of these conditions are complied with that a hardening operation may be considered successful. The proper hardening heat is very well defined within certain limits, both upwards and downwards, the lower limit being the temperature required in order to effect a transformation of the cement carbon into hardening carbon, below which there cannot be any hardening at all, except a certain hardness mechanically effected in consequence of the sudden cooling, and the upper one being the temperature which should not be exceeded in order to avoid the formation of a more or less coarsely crystalline structure, thus rendering the steel brittle, and at the same time hard. In the following Table are given some comparative results obtained by hardening at too high and too low temperatures, as well as at the proper hardening temperature.

TABLE 5.

Influence of Hardening Temperature on Hardness Result.

Specimens after being heated up to the respective temperatures here indicated, quenched with water + 20° C.

Steel.				Hardening temperature, 690° C.		Hardening temperature, 750° C.		Hardening temperature, 1000° C.	
No.	C. per cent.	Si. per cent.	Mn. per cent.	Diameter of Impression.	Hardness Number.	Diameter of Impression.	Hardness Number.	Diameter of Impression.	Hardness Number.
				Mm.		Mm.		Mm.	
1	·10	·007	·10	5·15	134	4·70	163	5·10	137
6	·65	·27	·49	3·95	235	2·85	460	2·95	430
6A	·66	·33	·18	4·05	223	3·10	387	3·10	387
7	·70	·32	·22	3·90	241	2·25	744	2·25	744

This Table is of special interest, because in it is given a steel with the extraordinary hardness of 744 Brinell number.

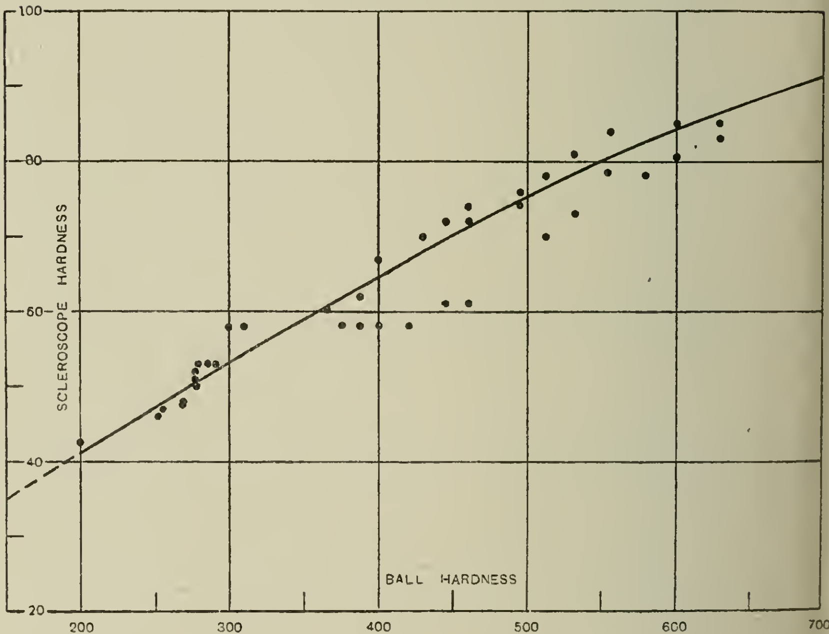
With regard to comparative tests, it might seem easy, when a certain Brinell ball number has been obtained, to translate it into a scleroscope number. To make a comparative Table was, however, not then practicable, and under present conditions the scleroscope results could not readily be converted into Brinell numbers. The following Table 6 and Fig. 10 (page 762) were given in order to show comparative numbers between Brinell ball and scleroscope —that is, scleroscope could be converted into ball hardness numbers and vice versa. It was of course understood that the Table was only put forward as an approximate one.

He (Sir Robert) had carried out some scleroscope experiments to determine the hardness of various minerals, so as to get some idea of the hardness of products of that kind as compared with metals. He had mentioned the subject to his friend Dr. Holloway,

TABLE 6.—*Comparison of Scleroscope and Ball Hardness.*

Ball.	Sclero-scope.	Ball.	Sclero-scope.	Ball.	Sclero-scope.	Ball.	Sclero-scope.	Ball.	Sclero-scope.
150	35	275	50	400	65	525	78	650	88
175	38	300	53	425	68	550	80	675	90
200	41	325	56	450	70	575	82	700	92
225	44	350	59	475	73	600	84		
250	47	375	62	500	75	625	86		

FIG. 10.—*Comparison of Scleroscope and Ball Hardness on a tempered Steel.*



who considered the work done would be of considerable value, so he would like to put them on record. The data have not to his knowledge been presented before, and he thought it might advantageously form part of the Report. Thirty-four specimens

were examined. One mineral he had not tested, namely, the diamond. He had endeavoured to obtain diamonds from those engaged in that industry, but they refused to let him have a diamond without a guarantee that he would not split it. He hoped some day—after the war—to carry out that test also!

In Table 7 was given a comparison of hardness determinations on different kinds of minerals with their corresponding position in the Moh scale, which has been used for so many years as a standard. As an example, he would say that:—

Talc	gives a scleroscope figure of 6.
Fluorspar . . .	an average figure of about 54.
Quartz . . .	varies from 80 to 100.
Common Window Glass .	shows as high as 112.
Lead Glass . . .	varies from between 80 to 90.

Direct Scleroscope Tests of Minerals and other Materials.—The tests given in Table 7 naturally varied to some extent, but were nevertheless very interesting. The variation is probably due to the irregular surface and the small size of some of the specimens. Even after careful polishing, the results were still somewhat irregular. For this reason, therefore, the highest readings only were taken into account; these are plotted on Fig. 11 (page 768). On the whole there appeared a fair agreement between the results obtained on his own specimens compared with those furnished by Dr. Holloway. It was remarkable to note that the scleroscope hardness fell off considerably after quartz—that is, for topaz and corundum. It would be noticed that no tests had been made on diamond, but these ought certainly to be carried out if it were possible to obtain the loan of a few of these valuable products.

Fig. 12 (page 769) showed the results of the hardness tests by other experimenters by various methods, and formed an interesting comparison. They were all, more or less, scratch methods, so naturally showed continuously increasing hardness.

The tests on miscellaneous materials were interesting, and bore

(*Continued on page* 768.)

TABLE 7.—*Scleroscope Hardness of the Minerals of Moh's Scale and other Materials.*

(The results on Minerals of Moh's Scale are plotted on Fig. 02.)

Hadfield's No.	Holloway's No.	Material or Mineral.	Description.	Source.	Moh's Scale No.	Surface.	Scl. Figure. Highest.	Scl. Figure. Lowest.	Scl. Figure. Mean.	Remarks.
				Moh's Scale.						
1	—	Talc	—	Hadfield	1	Polished	No satisfactory reading.			
2	51	,,	Square lump	Holloway	1	,,	6			
3	51	,,	Foliated; Tyrol	,,	1	,,	8			
4	—	Selenite	—	Hadfield	2	Crystal face	23	18	20	Splits under test.
						Polished	19	16	18	
5	41	,,	Long crystal	Holloway	2	Crystal face	12	9	10	
6	41	,,	Small crystal	,,	2	,, ,,	$12\frac{1}{2}$	$10\frac{1}{2}$	11	
7	—	Calcite	Crystal	Hadfield	3	Crystal face	44	—	—	Splits under test.
						Polished	52	49	51	
8	44	,,	Large broken pieces	Holloway	3	Crystal face	42	29	36	
9	44	,,	Small cleavage pieces	,,	3	,, ,,	39	35	38	From face. Rather rough.
						,, ,,	38	33	$35\frac{1}{2}$	End face. Rather rough.

10	—	Fluorspar	Coloured crystal	Hadfield	4	Crystal face	24	—	—	Splits under test.
						Polished	62	45	51	
						Crystal face	57	53	54	
11	42	,,	Blue crystal	Holloway	4	,, ,,	56	53	54	Three faces.
						,, ,,	50	48	49	
12	42	,,	Polished bead	,,	4	Polished	64	59	60½	
13	42	,,	Green crystal	,,	4					
13A	42	,,	Clear crystal	Arnold	4	Crystal face	65			
						Cleavage face	47	42	45	Two different parts.
14	—	Apatite	—	Hadfield	5	,, ,,	57	53	55	
						Polished	58	55	57	
15	45	,,	Large green lump	Holloway	5					
16	45	,,	Small grey crystal	,,	5		61	60	60½	
17	—	Felspar	—	Hadfield	6	Crystal face	82	65	73	
						Polished	87	79	84	
18	43	,,	Large red lump	Holloway	6	Cleavage face	93	67		
19	43	,,	Small buff crystal	,,	6	Crystal face	93	81	—	Two opposite faces.
							85	52	—	

(Sir Robert A. Hadfield.)

TABLE 7 (*concluded from previous page*).

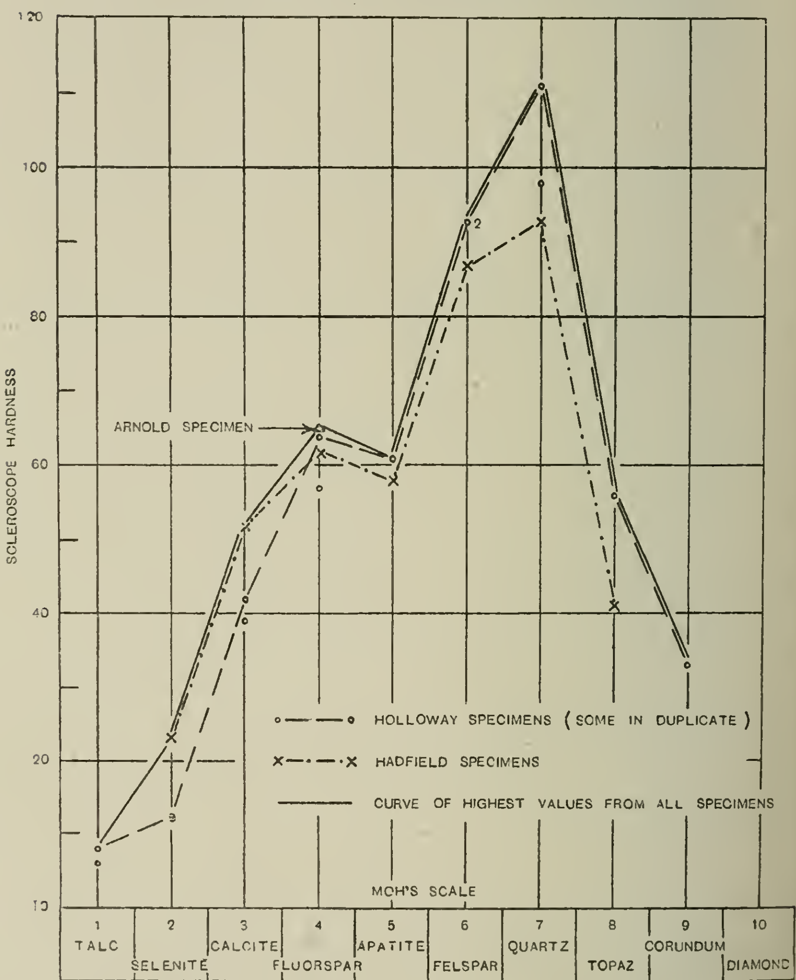
Hadfield's No.	Holloway's No.	Material or Mineral.	Description.	Source.	Moh's Scale No.	Surface.	Scl. Figure. Highest.	Scl. Figure. Lowest.	Scl. Figure. Mean.	Remarks.
20	—	Quartz	Crystal	Hadfield	7	Cleavage face	72	67	68	
						Polished	93	63	$83\frac{1}{2}$	
21	40	,,	Nodular fragment	Holloway	7	Polished	111	98	104	
22	40	,,	Crystal	,,	7	Crystal face	98	93	95	Clear part.
							98	94	96	Milky part.
23	—	Topaz	Small crystal	Hadfield	8	Crystal face	38	29	$31\frac{1}{2}$	
						Polished	41	38	39	
24	48	,,	Crystal	Holloway	8	Crystal face	56	23	$42\frac{1}{2}$	Four different places.
							59	19	43	
							34	20	28	
							42	28	33	

25	—	Corundum	Rough piece	Hadfield	9	Rough surface	22			
26	—	,,	Flat green ; Ontario	Holloway	9	Cleavage face	33	25	30	Embedded on pitch.
						,, ,,	13	10	11½	On steel surface.
27	—	,,	Small pink ; India	,,	9					
				Miscellaneous Minerals.						
30	46	Jasper	Red Aberdeen ; Carnarvon	Holloway	—	Fracture	97	94		
31	49	Aquamarine	Crystal	,,	—	Crystal face	96	90	92	
40	50	Agate	—	,,	—	Polished	111	102	106	
				Miscellaneous Materials.						
		Glass.	Window glass	Hadfield	—	—	123			
32	—	,,	,, ,,	Holloway	—	—	113	112		
		,,	Plate glass (not lead)	—	—	—	109	—	—	Splits under test.
37	—	Lead glass	Tube	—	—	—	93	92		
39	—	—	Bohemian ; G & B	—	—	—	80	78		

(Sir Robert A. Hadfield.)

out the fact that there was no true relationship between scratch hardness and scleroscope hardness. For example, window glass,

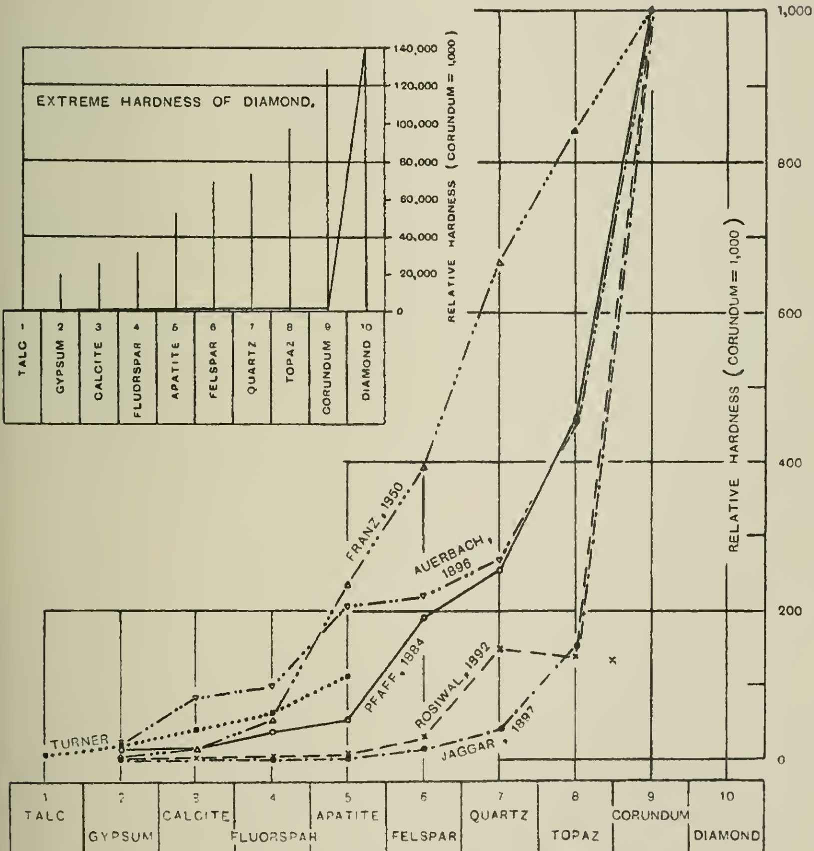
Fig. 11.—*Scleroscope Hardness of the Minerals of Moh's Scale.*



which gave a fairly regular reading of about 120, was scratched by felspar but not by apatite—that is, Moh's hardness No. $5\frac{1}{2}$.

Fig. 11 indicated a scleroscope hardness of less than 80. Further tests on agate with a proper bearing surface gave a maximum of 111.

Fig. 12.—*Hardness of the Minerals of Moh's Scale as determined by various Experimenters.*
Corundum = 1,000.



Indirect Comparison of Scleroscope and Moh's Scale by Tests on Steel Specimens.—Specimens of known scleroscope hardness were tested against the minerals of Moh's scale by scratch method, and their Moh's hardness number determined and plotted against the

(Sir Robert A. Hadfield.)

Fig. 13.—*Relation between Scleroscope Hardness and Moh's Scale.*

Obtained by comparing Shore Scleroscope with Scratch Tests on Nickel-Chromium Steel.

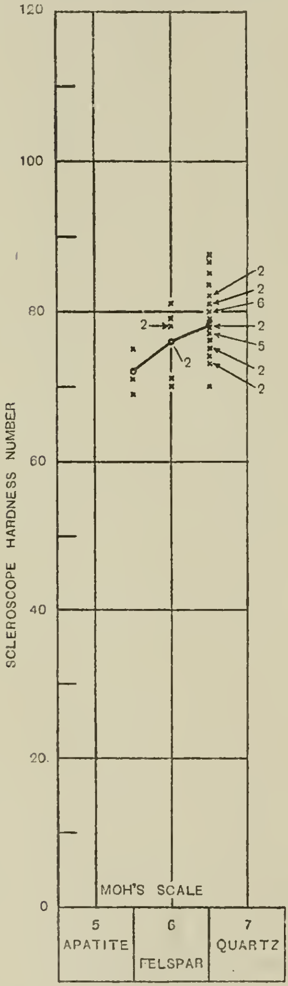


Fig. 14.—*Relation between Ball Hardness and Moh's Scale.*

Obtained by comparing Brinell with Scratch Tests on Nickel-Chromium Steel.

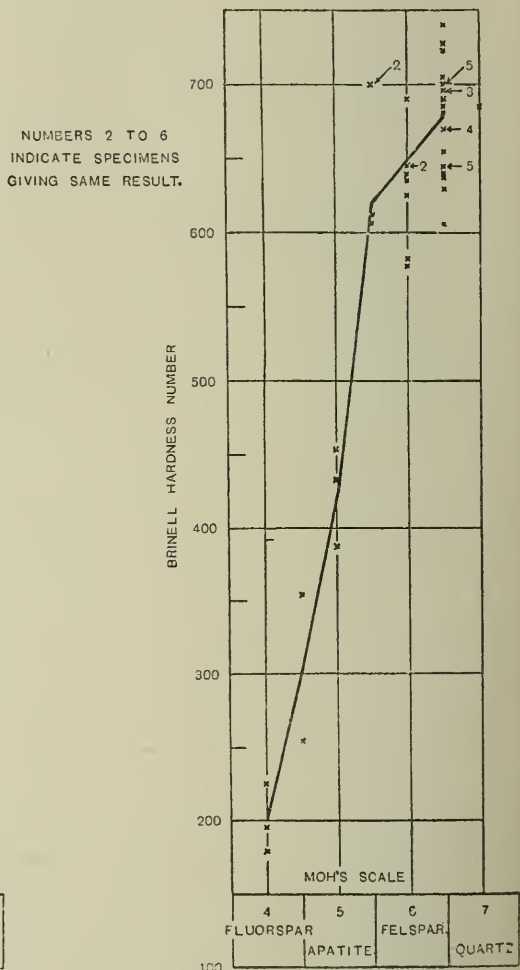


TABLE 8.—*Comparison of Shore Scleroscope and Moh's Hardness Scales, by Scratch Tests on Steel Specimens of various Scleroscope Hardness.*

Test Piece No.	Moh's Hardness Number.								
	$3\frac{1}{2}$	4	$4\frac{1}{2}$	5	$5\frac{1}{2}$	6	$6\frac{1}{2}$	7	$7\frac{1}{2}$
		Fluorspar		Apatite		Felspar		Quar[illegible]	
		Nickel Chrome Steels.							
4826						79			
4827							$83\frac{1}{2}$		
4825							$87\frac{1}{2}$		
4828							77		
4823							85		
4821							$86\frac{1}{2}$		
4824							81		
4822							$78\frac{1}{2}$	82	
6392								82	
6393						81			
4778					75				
4779							80		
4775							77		
4773						70			
4777						78			
4776						76			
4774						78			
4741							78		
4742							81		
4743							80		
6226						76			
4745							75		
4744							80		
4746							82		
4747							80		
4748							80		
4749							77		
4750							73		
A6177					69				
4752						71			
4753					71				
4754							78		
4755							75		
4756							77		
4757							70		
4758							77		
4759							82		
4760							76		
4761							80		
4762							74		
4763							73		
4764							79		
	Average	—	—	—	72	76	78	82	
		Carbon Steels.							
S.S. 2439			53				105		

(Sir Robert A. Hadfield.)

TABLE 9.—*Comparison of Brinell & Moh's Hardness Scales, by Scratch Tests on Steel Specimens of various Brinell Hardness.*

Test Piece No.	Moh's Hardness Number.								
	3½	4	4½	5	5½	6	6½	7	7½
		Fluorspar		Apatite		Felspar		Quartz	
				Nickel Chromium Steels.					
4826F						645			
4827F							696		
4825F							728		
4828F							680		
4823F							723		
4821F							740		
4824F							696		
4822							645		
6392								685	
6393						635			
4778					612				
4779							696		
4775							645		
4773						577			
4777						640			
4776						645			
4774						690			
4741							700		
4742							700		
4743							685		
6226						582			
4745							640		
4744							645		
4746							706		
4747							700		
4748							690		
4749							655		
4750							630		
A7231				454					
A7230				433					
A4735				387					
A4637			355						
A7357			302						
A4706			255						
A4834		228							
A2309		196							
A7185		179							
A6177					700				
4752						625			
4753					606				
6178					700				
4754							700		
4755							670		
4756							670		
4757							645		
4758							637		
4759							700		
4760							670		
4761							670		
4762							645		
4763							606		
4764							700		
	Average	201	304	425	654	629	677	685	
				Carbon Steels.					
S.S.							742		
2439			351						
				Manganese Steels.					
							408		
						438			
					380				
					360				
				368					
				393					

scleroscope hardness on Fig. 13 (page 770). Individual figures were shown on Table 8 (page 771). These specimens only comprised a short range in hardness, but the scleroscope figures for corresponding Moh's scale hardness obtained by this method were appreciably lower than the figures obtained by the above method, shown on Fig. 11 (page 768).

Indirect Comparison of Brinell Hardness and Moh's Scale by Tests on Steel Specimens.—A similar method was followed as in the case of scleroscope hardness over a wider range of steel specimens, including the specimens used above for scleroscope test. The results were given on Table 9 (page 772), and plotted on Fig. 14. A fairly approximate relation was obtained. It was interesting to note that the range covered by ball hardness figures from 200 to 700 was all comprised on Moh's scale between the minerals fluorspar and quartz. No direct determination of the ball hardness of the minerals could be made owing to their brittleness. The material possessing some ductility was essential for this type of testing.

Mr. Joseph Langston wrote that the Report dealt with a subject of great importance to all mechanical engineers, who were indebted to Dr. Stanton and Mr. Batson for the long series of experiments and the interesting way in which the results had been presented. These showed the resistance to wear of various samples of steel and bronze, in a dry state, in sliding contact with a standard hardened steel-ring, and in many cases they were certainly remarkable in the extreme variation of apparently similar materials. In practice, every effort was made to keep metals sliding on each other separated by a film of oil, and it was just at the time when this failed that abrasion occurred, so that the new tests helped in the choice of metals to withstand such conditions. It was usually assumed that hardened pieces made out of the same steel in lubricated sliding contact did not give such good results as those of differing composition, and if this proved to be true, it would be necessary to test metals in pairs to arrive at results for practical use.

(Mr. Joseph Langston.)

Nothing was said in the Report about the steel from which the hardened test-ring was made, so that it was difficult to judge whether its relation to the specimens tested had any effect on the results. The point could be easily proved by making a further series of tests with a few of the steels listed in Table 4 (page 700), using a different wearing ring, and it would be interesting to see if the resulting figures were still in the same proportion.

Dr. A. E. H. Tutton wrote that the results of Dr. Stanton and his co-worker at the National Physical Laboratory appeared to him to be satisfactory, as far as could be expected. For Sir Robert Hadfield, in Appendix II, expressed the main difficulty before the work of the Committee, namely, the fact that industrial metals, whether more or less pure metallic elements or alloys, by their very mode of treatment in preparation for industrial or armament purposes, were more or less (and chiefly more) unhomogeneous. Their surface was often, and almost generally, specially hardened compared with the interior, and even if not so the first effect of a test like indentation was to render them so locally, and at the very spot where the test was applied. Especially was this so with manganese steels. It would, of course, be understood that in the writer's definition of hardness in Appendix III (page 712) he was dealing only with truly homogeneous solids, the ideal case which was rarely, if ever, attained or desired in industrial preparations of metals and alloys.

With respect to the remarks of Dr. Hatfield and Dr. Thompson concerning the writer's statement at the close of Appendix III that "high specific gravity (density) is generally accompanied by great hardness," the fact just mentioned should be borne in mind, and it was expressly stated in the Appendix that "the perfect solid—a crystal"—was referred to. Comparisons of steels or of rocks were absolutely excluded, for they were non-homogeneous, besides being composed of innumerable individual crystals which, even when of similar or identical chemical constitution, were promiscuously orientated with respect to each other. Moreover, there could be no question of a space-lattice in the case of glass; a space-lattice

only existed in the case of a crystal, and the writer's statement referring to the space-lattice was quite accurate.

The case of diamond and barytes was obviously a notable exception to any sweeping generalization as to hardness accompanying density, and it was perhaps not made sufficiently clear that such sweeping comparisons of substances so totally opposite in constitution —one a non-metallic element of low atomic weight, and the other a salt of a relatively heavy metal—were not contemplated. The writer had in mind cases in which other things were more or less equal, cases of more or less similar constitution. For instance, the two crystalline forms of carbon itself, diamond and graphite, of densities 3·52 and 2·29, and hardnesses 10 and 2; aragonite and calcite, the two crystalline forms of $CaCO_3$, of densities 2·95 and 2·72, and hardnesses 3·8 and 3·0; and the three forms of TiO_2, rutile, brookite and anatase, which were endowed with the densities 4·26, 4·15, and 3·90, and the hardnesses 6·3, 6·0, and 5·8. Corundum (sapphire and ruby) was also an excellent example of a crystalline substance involving no heavy metal, yet possessing both high density (4) and great hardness (9).

As regards Dr. Thompson's remarks concerning the relation between hardness and atomic volume, the writer was glad attention had been called to it. It was pointed out as long ago as 1852 by Kenngott, and amplified in 1868 by Schrauf, who showed that cubic substances of analogous composition and series of isomorphous chemically similar substances exhibited degrees of hardness which were inversely proportional to their atomic volumes (or as we should now say, molecular volumes). Thus in the cases of galena PbS, Greenockite CdS, and zincblende ZnS, the molecular volumes were 31·8, 29·9, and 24·0, and the hardnesses were 2·5, 3·3, and 3·8. These facts were considerably extended by Professor Turner in 1909, as stated by Dr. Thompson.

He felt, too, that the question of hardness was most intimately bound up with the other physical properties mentioned by Sir Robert Hadfield, and perhaps more than had been appreciated, with elasticity. Some day, when he had more leisure, he was hoping to carry out with his elasmometer—the delicate interferometric (wave-

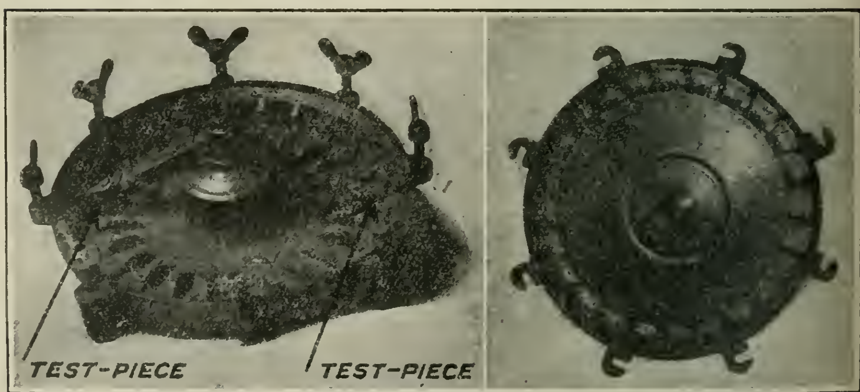
(Dr. A. E. H. Tutton.)

length of light) apparatus for measuring the elasticity of small bodies (rare metals obtainable only in small quantities—for instance, in pieces quite as small as crystals) which he described to the Royal Society—a complete set of determinations, in wave-lengths of light, of the bending, and hence the elasticity of all the known metals and alloys, including industrial products. This instrument, on which the writer had spent nearly £400, was probably the most delicate, accurate, and efficient for the purpose in existence, and ought to give results of value. A test research with pyrites crystals had already afforded most satisfactory results.

Dr. T. E. Stanton wrote, in reply to Mr. Joseph Langston's remarks on the material used for the test-ring, that this ring was made from the same steel as specimen No. 21, 1908 D in Table 2 (page 696). Sir Robert Hadfield informed him, however, that the hardening conditions were not precisely the same in the two cases. The ring was heated and semi-quenched for a few minutes and then cooled in an air-blast. Specimen No. 21 was heated to a white heat and cooled in an air-blast.

Dr. F. Rogers, in continuation of his remarks (page 757), sent an illustration of his abrasion testing-machine, Fig. 15, with description, as follows:—

Fig. 15.—*Abrasion Testing-Machine.*



Two specimens, in the form of disks $\frac{1}{2}$ inch diameter, $\frac{3}{16}$ inch thick, can be tested simultaneously. They are carried at the ends of the two arms revolving in the casing, which has fixed ribs placed to prevent general swirl of the mixture of water and abrasive (coarse emery) with which it is partly filled. Thus the specimen is continually coming into violent contact with the suspended emery grains. The specimen is weighed before and after running for a definite time (10 minutes, for example) at a definite speed (1,500 revolutions per minute). The loss of weight is a measure of the hardness. After each test, the machine is rinsed out and a fresh small measure of emery used for each test.

The following communication was received on going to press :—

Professor H. Le Chatelier wrote that hardness could not be measured, any more than the force of hurricanes at sea or courage in men. These were complex phenomena resulting from numerous elementary facts which varied independently of one another, so that as a whole they could not be measured. The force of a hurricane, for instance, depended upon the velocity of the wind, the height of the waves, and their frequency, and upon undercurrents.

Two simple characteristics determined whether a quantity might be measured or not. If measurable, it should satisfy the laws of equivalence and accumulation (*aditivité*). Temperature, though it followed the law of equivalence, did not follow that of accumulation. For instance, two bodies raised to the same temperature would not give a higher temperature if brought together. So that temperature could not be measured—all that could be done was to register it on certain scales, and there were as many different scales as required for different modes of comparison. But though these scales were different, they might be compared with one another and a correlation established about the figures.

Hardness was precisely the quantity which followed neither the law of equivalence nor that of accumulation. Two bodies giving the same hardness result under the Brinell ball-test gave different

(Prof. H. Le Chatelier.)

results if scratched or abraded as in Dr. Stanton's tests. Not only was it impossible to measure hardness, but the different tests had no relationship between them.

To understand the phenomena completely, the problem should be studied from a different point of reference. For instance, analogous results should be classified separately, as capable of co-ordination, against results which differed totally from one another. Hardness, for instance, could not be measured by tensile and compression tests. It would be found that steel containing 1 per cent. carbon, when tempered at 800° C. and not annealed, had a lower tensile limit than if annealed at 300° C. For compression tests, the results might be reversed; they would be surely reversed if the specimen were scratched.

The Brinell and Shore tests should, generally speaking, give comparable classifications, but not in an absolute way, for in the case of the Brinell ball, the deformation, and therefore the amount of screwing (*écrouissage*), should be greater than in the case of Shore's scleroscope. Hadfield steel should appear relatively harder under the Brinell's test than under the scleroscope.

In the same way, time exercises were influence. Zinc, the deformation of which was a function of time, should appear relatively harder under the scleroscope than under the Brinell test. Again, crystallized bodies, and bodies that could be split like cementite, would be relatively harder under wearing by rubbing than under the ball-test.

The problem therefore seemed to be to establish two or three methods of reference for hardness, giving as widely different results as possible, so that hardness (which was an essentially complex phenomenon) might be studied under all its phases. Afterwards, for each particular application, the reference method which was most applicable to the conditions might be used.

The Institution of Mechanical Engineers.

PROCEEDINGS.

December 1916.

An Ordinary General Meeting was held at The Institution of Civil Engineers, London, on Friday, 15th December 1916, at Six o'clock p.m.; Michael Longridge, Esq., *Vice-President*, in the Chair.

The Minutes of the previous Meeting were read and confirmed.

The Chairman announced that the following eighty-three Candidates had been duly elected:—

MEMBERS.

Borain, Joseph Edward,	Durban.
Collitt, Sydney,	Lincoln.
Grieve, Charles James Kerr,	Kuala Lumpur
Hefford, Alfred Edwin,	Saxilby.
Law, Léon Walter,	Charkov, S. Russia.
Martin, William,	Germiston.
Matthews, Wilfrid Joseph, Captain, R.E.,	Gibraltar.
Munro, William,	Bristol.
Newson, Henry James,	Bristol.
Seaton, George Frederick,	Woolwich.
Taylor, John Reginald,	Topohanchi, India.

ASSOCIATE MEMBERS.

Anderson, Sydney Drummond, Lieut., R.E. (T.F.),	B.E.F.
Badger, William,	Rotherham.

Bales, Frederick George,	London.
Bamford, Herbert,	Suez.
Chate, Raymond Victor,	Aldershot.
Collette, Henry Hastings,	Colombo.
Cooper, John,	Hull.
Corben, Wilfrid George Ayling, Staff Sergeant,	Cape Town.
Das, Manmatha Nath,	London.
Dorsett, Wilfred Braybrook,	Woolwich.
Foulis, Wilfrid Venour, Captain, A.S.C.,	B.E.F.
Gledhill, Charles,	Castleford.
Goulden, Charles Herbert, Lieut., R.G.A.,	Croydon.
Greenwood, John Dennis,	Braintree.
Hurll, James,	Sydney.
Jockel, Lauret Marshall, Lce. Corp., R.E.,	Edinburgh.
Jones, John Herbert,	Birkenhead.
Jordan, Gilbert Lewis Arratoon,	London.
Lecoche, Jules,	Armentières.
Low, Kenneth Stewart,	London.
Meyjes, Anthony Charles Dorian,	Luton.
Mills, Philip,	Port Stanley, F.I.
Murrell, Frederick Edmund,	Calcutta.
Nops, Vivian Douglas, Eng. Lt.-Com., R.N.,	H.M.S. *Dominion*.
Ogilvie, Alexander,	London.
Oubridge, William Arthur,	Coventry.
Petrie, Norman Charles, Lieut., R.E.,	London.
Ranson, George Sylvester,	Thornhill.
Rawlings, Percy Townley, Lieut., R.N.V.R.,	Sheerness.
Rees, John William,	Farnborough
Ritchie, Frederick George,	Singapore.
Robertson, Cyril Ernest,	London.
Rose, Nathaniel,	London.
Rowles, Alec Henry, Sergeant, R.E.,	B.E.F.
Sharp, Henry Hey,	Stratford, N.Z.
Short, Andrew Armstrong,	Derby.
Skinner, Louis Arthur,	London.
Slater, Alexander Fredrick,	Aligarh, India.
Smart, Richard Wensley, Lieut.,	Penarth.
Smartt, Thomas William,	London.
Smith, Ernest Wentworth,	London.
Tann, John Laurance, Lieut., A.O.D.,	Woolwich.
Thomas, William Strother,	Salford.
Thorpe, Thomas Smyth,	Calcutta.
Tindle, Stuart Pike, 2nd Lieut., R.H.A.,	Swindon.
Twells, John,	Lincoln.
Upham, William, Lieut., R.A.,	Sheerness.
Walker, James Scarlett Ascroft,	Wigan.

Wallace, Archibald, ...	Melbourne.
Walsh, William Dixon, ...	Huddersfield.
Walters, Ernest Albert, 2nd Lieut., R.E.,	Carnarvon.
Wickham, Oliver, ...	London.
Williams, James Heyward, . . .	London.
Williamson, Griffith Evans, . . .	Barrow-in-Furness.
Womersley, William Dobson, . . .	Halifax.

GRADUATES.

Bracegirdle, John, ...	Bolton.
Chick, Thomas William, . . .	Weymouth.
Favell, Frederick, ...	Lincoln.
Forsyth, Philip, ...	Kingston-on-Thames.
Gamble, Charles Frederick Snowden, .	Stockport.
Gomez Menendez, Alfonso, . . .	Oviedo, Spain.
Hanson, Richard Greenwood, . . .	Wembley.
Hebdon, Edward Alan William, Sapper R.E., ...	London.
Hesketh, John, ...	Accrington.
Isaac, Archibald Charles Thompson, .	London.
Lewis, David, ...	Shrewsbury.
Roberts, John, ...	Manchester.
Russell, George Alexander Vincent, Sapper R.E., ...	Warrington.
Shephard, Thomas Terence, . . .	London.
Thomas, Leonard Howard, . . .	Birmingham.
Vincent, Edward Thomas, . . .	Rochester.
Wind, Hubert, ...	Manchester.

The Chairman announced that the following three Transferences had been made by the Council :—

Associate Members to Members.

Armitage, Charles Varley, . . .	London.
Burne, Edward Lancaster, . . .	London.
Schwenk, Frederick Louis, . . .	Briton Ferry.

The following Paper was read and discussed :—

"Variable-Speed Gears for Motor Road-Vehicles"; by Robert E. Phillips, *Member*, of London.

The Meeting terminated at a Quarter to Eight o'clock. The attendance was 45 Members and 46 Visitors.

VARIABLE-SPEED GEARS FOR MOTOR ROAD-VEHICLES.

By ROBERT E. PHILLIPS, *Member*, of London.

Introduction.—The rapid development of road locomotion after its renaissance, brought about in this country by the passing of the Locomotive and Highways Act of 1896, may be attributed to three primary causes: (1) the introduction of the high-speed petrol motor, (2) the state of perfection to which variable speed-gearing has been brought, and (3) the employment of pneumatic tyres. Although the high-speed internal-combustion engine has been dealt with in many Papers read before this and other Engineering Societies, the Author is not aware of any Paper which has dealt exclusively and fully with the various mechanisms which have been and are employed to give a variable velocity ratio between the prime mover and the road wheels of motor road-vehicles. In his opinion the bearing which the improvements in these mechanisms has had on the rapid development in road locomotion has not been fully recognized, and the perfection to which the variable speed-gear has been brought appears to have been overshadowed by the development of the prime mover.

The almost universal adoption of the high-speed petrol-motor as the prime mover in motor road-vehicles at once brought into

prominence the importance of devices for enabling the ratio of speed between the prime mover and the road wheels of the vehicle to be varied, by reason of the fact that the speed of maximum torque of a petrol-engine is practically at full power, and as the speed decreases so also does the torque. It may be remarked here in passing that, although the steam-engine, on account of its extreme flexibility, has been, and still is, successfully used in motor road-vehicles—more especially of the heavier class used for commercial purposes—it has been found advantageous even to fit such vehicles with a speed reduction gear to meet the ever-varying exigencies of load and road. In the earlier motor road-vehicles of the renaissance period variable speeds were obtained either by the use of a plurality of pulley and belt transmissions, or by the use of shaft-to-shaft gearing in which the wheels are engaged by a side movement—that is, in a direction parallel to the axis of the shafts. The former may be said to represent the German school, as instanced by the Benz and the Canstatt-Daimler vehicles, and the latter the French school, as instanced by the Panhard and the Peugeot vehicles.

Pulley and Belt Transmission Gear.—This is so well known that it is only necessary to state that it has been used with different-sized pulleys, with stepped pulleys, and with coned pulleys. Except for very light motor-vehicles, such as motor-bicycles and so-called cycle-cars, the use of this type of transmission is a thing of the past.

Shaft-to-shaft Gearing.—Although opposed to all mechanical principles, the side meshing type of spur-wheel gearing, in which the various trains of wheels are brought into engagement by "end-on" or clash engagement, has, by the perfection to which its design has been brought, by the high standard of workmanship employed in its manufacture, and by the use of the highest grade of materials, been developed into a completely satisfactory piece of mechanism. Although, from an engineer's point of view, it is theoretically an embodiment of everything that is wrong, in practice it has proved to be "not so bad as it looks on paper,"

and the fact that it has successfully held its own for nearly twenty years against many other gears which, theoretically, should give better results, is testified to by the fact that at least 90 per cent. of the motor road-vehicles manufactured in this country are fitted with this type of gear.

It is, however, only fair to say at once that the position which the sliding type of gear now occupies is due to a very large extent to two factors: (1) that nothing like the same amount of attention has been directed to any other type of gear as has been brought to bear on this particular type, and (2) that the motors now used are of such a high horse-power that at least 75 per cent. of the running is now done on the direct drive. Mr. F. W. Lanchester—a Member of this Institution—in his Presidential Address before the Institution of Automobile Engineers, tersely summed up the position of the sliding type of gear in these words: "The sliding type of change-speed gear has ceased to be objectionable to the extent that we have given up using it"—an opinion as true as it is concise.

Panhard Gear.—In the original gear of this type,* introduced about the year 1894 by the firm of Panhard and Levassor, of Paris, and commonly known as the Panhard gear, all the sliding wheels were mounted on a common element, so that it was necessary to run through the intermediate gears to get from the lowest to the highest gear and *vice versâ*, and consequently it is known as the "straight-through" type, in contradistinction to the "selective" type now in almost universal use.

Renault Gear.—About the year 1890 the firm of Renault Frères introduced a construction of change-speed and transmission gear which may justly be said to have revolutionized the design of the transmission mechanism of the modern motor road-vehicle, as at least 90 per cent. of the motor road-vehicles driven by internal-combustion engines at present constructed embody one or other of the features of this gear. Instead of transmitting the power from the gear-box to the road wheels by means of a differential countershaft

* *See* Appendix, Fig. 1 (page 806).

and chain gearing, the road wheels in the Renault system are mounted on a live differential axle which is coupled to the driven shaft of the gear-box by means of a longitudinally arranged shaft, commonly called a propeller-shaft.

The Renault gear not only provided for a direct drive between the driving and driven shafts—which is now considered a *sine quâ non* in all gears of the sliding type, as it materially reduces both friction and noise—but it also rendered the lay-shafts not only idle but also quiescent during the direct drive. A further advantage of the Renault construction of gear is that the length of the gear-box can be reduced to a minimum, as there is no necessity for any clearance between the different gears, owing to the wheels of the different trains being entirely out of mesh before and when the sliding element forming the clutch coupling is moved. An example of this gear is given in the Appendix, Fig. 2 (page 807).

Daimler Gear.—The advance that has been made in the side meshing type of gearing will best be realized by comparing the original Panhard gearing, Fig. 1 (page 806), with an up-to-date gearing as exemplified in the modern Daimler gear, which is described in the Appendix, Fig. 3 (page 808).

The Daimler gear embodies two important features not to be found in the Panhard construction, namely, the placing of the driving and driven shafts of the gear in axial alignment, and the employment of more than one sliding element. The first of these two features enables the driving and driven shafts to be connected together by a direct couple, so that a through or direct drive from the engine to the transmission gearing can be obtained; and the other feature enables any desired gear to be obtained without running through any other gear. This type, which is known as the "selective" type, has entirely superseded the "straight-through" type, as it not only reduces wear and tear on the teeth of the wheels, but enables the over-all length of the gear-box to be materially shortened, which stiffens the shafts, and by removing the tendency to whip, which throws the gears out of pitch, not only materially increases the mechanical efficiency of the gear but

also reduces noise. The junction of the driving and the driven shafts and the spur-wheels permanently gearing the driving shaft with the lay or countershaft are arranged at the front end of the gear-box, and the sliding element is mounted on the driven shaft. This allows the countershaft to be geared down in relation to the driving shaft, with the result that when the driving shaft is coupled direct to the driven shaft to obtain the direct or through drive, the countershaft and the wheels on it are rotating at a minimum speed. This was at one time thought to be of considerable importance, not only on account of the reduction of friction set up by the revolving parts, but also on account of the power lost by the churning up of the oil or grease in the box; but latterly, since the introduction of anti-friction bearings for the shafts and the use of thin oil as a lubricant, the opposite construction, in which the junction of the two shafts and the train of wheels permanently gearing one of the shafts to the countershaft are arranged at the back end of the box, has been adopted in order to reduce the noise to a minimum when the car is at a standstill with the engine running and the clutch between the engine and the gear-box is left in engagement, which is the usual condition of things when a car is making a temporary stop. Under these conditions the countershaft and all the wheels on it, together with the wheel on the driven shaft which drives the countershaft, are at a state of rest.

From a comparison of the two types of gear illustrated in Figs. 1 and 2 (pages 806–7), it will also be observed that each has an advantage over the other with a corresponding disadvantage. In the former the power on all the speeds is transmitted through one pair of gear-wheels, so that the frictional losses due to the gearing are the same on each speed, while in the latter type the power on one speed is direct, that is without going through any gearing, but on the other speeds the power is transmitted through two pairs of gear-wheels, so that on all speeds other than the direct one there is twice as much frictional loss as in the type of gear illustrated by Fig. 1. This naturally directs attention to the fact that the direct drive should give the ratio of speed between the

engine and road wheels best suited to each particular vehicle and the work it is called upon to perform. The general practice is to give the direct drive on the top or highest speed, and this is probably the best all-round practice for gears which give only three forward speeds; but when four forward speeds are provided the direct drive is sometimes on the third speed, the fourth speed—which in this case is a geared-up one—being only intended to be used under the most favourably running conditions.

The use of a plurality of sliding elements necessitates the use of a particular form of controlling mechanism as each change of gear involves two distinct movements, one to pick up the particular rod controlling the sliding element giving the desired gear, and the other to impart the necessary movement to the controlling rod. This is effected by giving to the control-lever two movements, first a lateral one in line with the axis of its pivot, and secondly a rocking one at right angles to the axis. This involves the use of a guide for the control-lever having two longitudinal slots and a transverse connecting slot, hence the appellation "gate-change" usually associated with this mechanism. This was first introduced into this country on the German Daimler cars known as the Mercedes, in the form shown in Figs. 4, 5 and 6 (Appendix, page 809), which is for a gear-box having three forward speeds and a reverse which are controlled by two sliding elements, one of which gives the top and second speed, and the other the first speed and the reverse.

Prevention of Wear on Teeth.—The prevention of undue wear and tear on the teeth of the wheels, due to the clash engagement, has been the desideratum of all designers of this type of gear, and the problem has been tackled in many different ways. The earliest method adopted was to keep the various trains of wheels constantly in mesh, one wheel of each train being loosely mounted on its shaft, and to provide independent sliding claw clutches for completing the driving couples between the wheels and their shafts. This construction had the defect that it seriously increased the over-all length of the box and thereby increased both its weight

and the cost of production. In a modification of this construction internal coupling devices were employed, but while these did not increase the length of the box they involved considerable complication. In another system the wheels on the countershaft were loosely mounted on the shaft, and an automatic driving couple was provided between each wheel and the shaft by means of a one-way clutch, so that the shaft could over-run the gear wheels but the wheels could not drive the shaft. The complications involved in this system were quite sufficient to condemn it.

Weller Gear.—According to another system, the sliding wheels are mounted loosely on their shafts and are brought into mesh with the respective corresponding wheels of their trains before they become coupled to the shaft on which they are mounted. Such a gear is the Weller, Fig. 7 (Appendix, page 811). As this gear is probably as cheap, if not cheaper, to make than the usual pattern of this type of gear, owing to the absence of a square or splined shaft and a similar sliding element, it is difficult to understand why it has not been more universally adopted, as it undoubtedly affords considerable protection to the teeth of the wheels from damage by careless or ill-timed changing, and consequently would not only wear longer but would make for sweetness and quietness of running and ease of manipulation.

Dux Gear.—Further development along this line of construction brings us to the Dux gear, Fig. 8 (Appendix, page 813). In this gear the wheels of all the trains producing the forward speeds are in constant mesh, and the sliding wheels themselves form parts of positive clutches, the other parts taking the form of internal toothed rings. This construction enables the box to be kept very short, and produces a very compact and robust gear, but it appears to be open to the objection that at all speeds all the wheels are running. This gear-box is fitted to the Caledon commercial vehicle in this country, and has been exclusively adopted by the Paris General Omnibus Company for their public service vehicles.

Other Forms of Gear.—It would be quite impossible, without unduly extending the length of this Paper, to attempt to describe all the various forms of this sliding type of gear. M. J. Rutishauser, an eminent French engineer, divides them into no less than 9 classes and 26 sub-divisions. Other variations to which passing reference may be made are :—

A construction in which there are two permanent trains between the driving shaft and the countershaft, either of which can be brought into operation. By this means two speeds can be given to the secondary shaft whereby the total number of indirect speeds obtainable is doubled.

A construction in which a plurality of secondary shafts are employed for the purpose of balancing the strains on the shafts and increasing the tooth surface without materially increasing the weight.

A construction in which the wheel on the countershaft of the permanent train between the driving shaft and the countershaft is loosely mounted on this shaft, and a clutch is provided for uncoupling it from this shaft when the driving shaft is coupled direct to the driven shaft to give the direct drive, so that during the direct drive only one of the gear-wheels on the countershaft is in motion.

A further development of the latter is a construction in which the wheel on the countershaft of the permanent train between the driving shaft and the countershaft is mounted to slide on this shaft, so that when the direct drive is in operation the wheel can be drawn out of mesh with the wheel on the driving shaft; whereby both the countershaft and all the wheels on it are quiescent on the direct drive. This would seem to be the ideal form of this type of gear, but difficulties occur in side meshing two sets of wheels at the same time which this form of gear entails.

The common practice with the sliding type of gear is to mount it in an independent box, which in some cases is made as a complete unit with the engine, but which is usually arranged at a convenient distance behind the engine and is connected with the driving axle carrying the road-wheels by means of a propeller-shaft. The enclosing and carrying of this shaft in a tube adapted to operate as

a torque member has led some designers to make the gear-box part either of the torque tube or of the casing enclosing the rear driving axle. The objection to mounting the gear-box either on the casing of the rear driving-axle or on the back end of the torque tube is that it increases the unsprung weight, but this is to some extent compensated for by the fact that the presence of a gear-box is considerably less evident to the occupants of a vehicle when it is located in this position than when it is mounted in the usual position on the frame of the chassis. This is probably due to the reduction of tremor, owing to the better isolation of the gearing from the body of the vehicle. The drawback of increasing the unsprung weight is, however, considerably modified when the gear-box is carried on the forward end of the torque tube, which is a practice that has much to commend it.

When the gear-box is an independent unit, it is of importance that it should be so mounted as to prevent any binding on the shafts due to distortion of the frame of the chassis. Either a spring suspension or a three-point suspension is usually adopted to this end. A convenient three-point suspension consists in carrying the gear-box fore and aft by means of trunnion bearings arranged concentric with the driving and driven shafts, and preventing rotational movement of the box by connecting an arm, extending from the side of the box, to the frame by means of a link.

Silence in Gear-Box.—The great desideratum in a gear-box is now silence, as it was not until the internal-combustion engine had been brought to a practical state of silence that the noises arising from the gear-box were fully realized. The noises from a gear-box may be divided into two classes. First, that produced by the running of the gears under load, which is more or less constant; and secondly, that produced by the clash engagement of the wheels or clutches, which is intermittent. While the former can be materially eliminated by careful design and workmanship, the latter must depend to some extent on the human element.

Dealing first with the noise produced by the running of the gears. It may be taken for granted, so far as present knowledge

goes, that spur-gearing of the sliding type cannot be made to run under load for any length of time without emitting a certain amount of noise, and that the problem of silent running depends to a very large extent on the care with which the gear is produced, and particularly so in relation to the teeth. To reduce the noise to a minimum, the following essentials must be observed: (1) the greatest care must be exercised in the production of the wheels, especially with regard to the teeth; (2) the box must have the necessary stiffness and its resonance be reduced as much as possible; (3) the shafts must be of ample diameter, be kept as short as possible, and be supported by a sufficiency of bearings so as to have a minimum of deflection; (4) the wheels must be small, in order to keep the peripheral speeds as low as possible; (5) the wheel centres must be absolutely accurate; (6) the wheels must be efficiently lubricated; (7) if ball-bearings are used, means must be provided to give some sort of a surface support in addition to the line contact of the balls in order to damp off the vibrations set up in the gear; and (8) single or double helical wheels must be used where possible.

As a certain amount of noise is inseparable from two spur-wheels running together under a load, however well and accurately they may be made, another form of drive must be employed if a really silent gear-box is required. The London General Omnibus Company arrived at this conclusion by force of circumstances, as they could not reduce the noise in their omnibus chassis sufficiently to get it passed by Scotland Yard until they substituted a chain-drive for the spur-wheel drive in their gear-boxes, and all of us are probably aware from actual experience how silent-running these omnibuses are on all speeds.

Chain Drive.—Chain-drive gear-boxes were used as far back as 1901 by Brooke, of Lowestoft; but these boxes were not particularly quiet, as chains of the roller type were used, whereas the silence of the modern chain-drive gear-box is due to the use of chains of the "inverted tooth" type. In the gear-box used on the London General Omnibus Company's "B" type of chassis, an improved

chain of the "inverted tooth" type, manufactured by the Coventry Chain Company, Limited, and known as the "Coventry Noiseless Chain," is employed, in which, for a given pitch, a rivet of larger diameter can be used, which not only increases the breaking load but also increases the wearing area of the rivet, the result being that a chain of but two-thirds the width of the standard pattern can be employed to transmit the same load. This firm has devoted considerable time and attention to the perfection of the chain-drive gear-box, and the problem they had to face was the finding of suitable wheels to run at a common centre distance to produce the desired speed ratios. That they have successfully tackled the problem is instanced by the large number of different designs of these gear-boxes that they have produced to meet the various demands of the automobile trade. One of these boxes is shown in Fig. 9 (Appendix, page 814).

In four-speed gear-boxes the additional speed is sometimes produced by an additional chain and pair of sprocket wheels, and sometimes by means of an additional spur-wheel on the countershaft with which the spur-wheel on the driven shaft employed for the reverse engages through an intermediate pinion.

In addition to the advantage of noiselessness, chain-drive gear-boxes have many other advantages, amongst which may be cited: (1) flexibility of drive, which also operates as a safety-valve and limits the destruction which a driver may cause by careless driving; (2) the obtaining of the speeds and the reverse with a minimum number of wheels; and (3) the ease with which chains can be replaced as compared with the replacement of a gear-wheel.

The noise produced by the clash engagement of the gears arises chiefly from the difficulty of getting the teeth of the wheels into engagement, and this seems to depend essentially on the pitch of the teeth, on the peripheral speed of the wheels, on the shape of the engaging edges of the teeth, on the speed at which the wheels can be brought into engagement, and on the force resisting the inter-engagement of the teeth. The accepted practice is to use wheels of small diameter so as to keep the peripheral speed as low as possible, to keep the pitch of the teeth relatively small,

and to round off the engaging edges or sides of the teeth. Although it is the common practice to round off the edges or engaging sides of the teeth, a much easier and quieter engagement results if the edges or engaging sides of the teeth instead of being rounded are chamfered or bevelled off, as this not only allows the teeth to become meshed to a greater depth before the drive comes on them, but also lessens the force resisting the complete meshing of the teeth, whereby the continued end-on movement necessary to bring the wheels completely into mesh is facilitated. This does not decrease the surface contact of the teeth subject to wear, if the edges or engaging sides are chamfered or bevelled off on one side of the teeth only.

Changing of Gear.—Various devices have been introduced in the transmission gear between the clutch and the driving axle carrying the road wheels, for the purpose of facilitating the changing of the gear, the most successful being a spring drive arranged between the clutch and the gear-box, and a secondary clutch arranged either in front of the gear-box to couple and uncouple the element of the main clutch carried by or coupled to the driving shaft of the gear-box, or at the rear of the gear-box to couple and uncouple the driven shaft of the gear-box and the propeller-shaft of the transmission gear, but these devices are outside the ambit of this Paper.

Automatic Gear-changing Devices.—Various systems have also been employed to make the changing of gears more or less automatic so as to eliminate the human element. All such systems embody two essential features, one a method of pre-selecting the gears and the other the method of timing their change. The automatic gear-changing devices which have attained any measure of success may be divided into three types: (1) the mechanically operated; (2) the electrically operated; and (3) the pneumatically operated. The first type may be divided into two classes: (*a*) those in which the clutch-pedal releases a spring which brings the gears into mesh, this spring being compressed by hand at the time the selection of gear is made; and (*b*) those in which the clutch-pedal operates the

gear. In this latter arrangement no springs are employed, the mechanism simply transferring to the clutch-pedal part of the operation which is usually performed by a hand-lever.

The Linley device, described in the Appendix (Fig. 10, page 816), which has for some years been successfully employed on the Commer cars, is an example of the mechanical type.

In the electric system the pull on the sliding elements of the gear is effected by solenoids which are brought into and out of action by means of switches suitably located so as to be operated by the driver of the vehicle, the arrangement being such that the switches merely operate as selectors for the particular gear desired, the actual closing of the energizing circuit being completed by the movement of the clutch pedal. Although this system has not been employed in any vehicles manufactured in this country, it has been successfully employed in several cars manufactured in the United States and imported into this country, of which probably the best known is the Cadillac. Electricity would seem to be better adapted for the purpose than compressed air, as a source of current is available on most modern cars, at all events of the pleasure type, whereas a compressed-air system, besides requiring an air-compression plant, involves a far more complicated construction, and unless the apparatus necessary for working this system can be made considerably more simple than that which has already been evolved, or the compressed air can be also utilized for some other useful purpose on the car, it does not appear to be a commercially practical proposition. The electric current required to operate these electric change-gear systems is so small as to be practically negligible. In a test of one of these devices drawing its current from an 80 ampère-hour 12-volt battery, 134,000 changes of gear were made without exhausting the battery.

The absence of noise with a direct drive gear has led some designers to provide a direct drive on more than one speed. A common method of obtaining two direct drives is to employ two crown wheels—of different diameters—on the differential box and two bevel-pinions on the propeller-shaft, suitable clutches being provided for coupling one or other of the pinions to the shaft.

This construction gives a direct drive at two different speeds, and when used with a gear-box has the additional advantage that it doubles the number of ratios of speed available. Some makers have adopted this system to obtain a direct drive on all speeds, but it has never been a commercial success, owing probably to the complication involved in providing suitable coupling devices for the driving pinions, to the fact that such a construction involves all the wheels of the gear constantly running, and to the increase of the unsprung weight on the back axle. One of the most successful of the direct-drive-on-all-speeds gear is that employed in the Sizaire-Naudin light car, Fig. 11 (Appendix, page 818). The Humphris gear (Appendix, page 819) is of a similar character.

The number and ratios of the gears depend essentially on four factors: the power of the motor, the size of the road wheels, the weight of the vehicle laden, and the nature of the roads the vehicle has to traverse; but even when these four factors are constant, a wide diversity of opinion exists as to both the best number and the best ratios. This much, however, may be said. The present tendency is to limit the number of gears to three and to reduce the gear ratio rather than increase it, and this latter probably arises from the desire to enable vehicles to travel on the direct drive for the greatest possible percentage of the distance travelled so as to avoid gear changing as much as possible.

The speed of the vehicle in relation to the speed of the engine is governed by the reduction in the final drive at the back axle, which is usually a single one. Some makers, however, employ a double reduction at the back axle, the merit of which—when used purely as a reduction gear—appears to be the ability to keep the wheels of each pair in the gear-box giving the various speeds of a more uniform size.

Before leaving this particular type of gear, which, as before stated, easily holds the first place in automobile construction, it will be well to tabulate both its advantages and its disadvantages. Its advantages are: (1) simplicity of construction, (2) comparatively light in weight, (3) easy to understand and manipulate, and (4) ease and low cost with and at which worn parts can be renewed. Its

disadvantages are: (1) abnormal wear due to the clash engagement of the teeth of the wheels, (2) liability to considerable damage by bad driving, and (3) noise. What further improvement can be made in this type of gearing seems to be "in the lap of the gods," but as far as it is possible to forecast, it would seem to lie in the direction of the use of some other or new metal or alloy for the box whereby increased stiffness and decreased resonance without increasing the weight will be attained, and in the all-round use of wheels having helical teeth.

Epicyclic Gear.—After the sliding type of shaft-to-shaft gear, the epicyclic gear has found most favour, and while this type of change-speed gearing has been successfully employed in some motor road-vehicles for many years, its application can only be considered as limited when compared with the sliding type of gear. While popular prejudice, which is always in favour of the thing which is known and understood, may account for its lack of adoption, it cannot be overlooked that as compared with the sliding type of gear, its cost of manufacture by reason of the necessity for a high standard of workmanship is relatively high, the number of its parts is comparatively large, it is difficult to obtain a useful ratio of speeds when three forward speeds are required without complication, and it calls for adjustment at intervals. Against these drawbacks it has several advantages over the sliding type of gear. For instance, it is practically silent on all speeds, it is less liable to break down or to be damaged through careless handling, and it is not subject to as much wear and tear. It will be seen, therefore, that while the disadvantages are nearly all matters for the manufacturer, the advantages are all on the side of the user. The best known gear of this type giving three forward speeds and a reverse is the Lanchester—Fig. 12 (Appendix, page 820)—which has been used continuously and to the exclusion of all other types of gear in the Lanchester cars since 1900.

The Ford car may also be cited as an automobile in which the epicyclic type of change-speed gear is exclusively used, and in this case the increased cost of production of this type of gear certainly

has not been a bar to its use, as the total cost of production of this car is known to be well below that of any other car of similar power and capacity, while its selling price has become a by-word. It must, however, be borne in mind that the gear fitted to the Ford car only provides two forward speeds.

Nothing is more fascinating than the possibility of effecting a smooth and gradual change of speed over the whole desired range, whereby the prime mover can always be kept running at its most effective speed. The exceedingly flexible petrol internal-combustion engine of to-day has eliminated much of the need that once existed for a gradual and infinitely variable change-speed gear, but the advantages of such a mechanism seem so apparent that much ingenuity has been exercised in the attainment of it.

Variable-Speed Mechanisms. — The various mechanisms for obtaining a gradual and infinite variable speed may be classified as follows:—

(1) A mechanical system in which expanding pulleys and belts are used,

(2) A mechanical system in which the drive is by frictional contact,

(3) A mechanical system in which the drive is on the feed-gear principle,

(4) An hydraulic system, and

(5) An electric system in which current generated by a dynamo driven by an engine is employed, either wholly or partially as the transmitting medium between the engine and the road wheels.

Belt Gearing.—Belt gearing is now only used on light cars of the so-called cycle type, and expanding pulleys are successfully employed to vary the speed ratio. These are almost invariably of the double-cone type, so that the belt used with them has the shape of an inverted truncated cone which gives the belt a better grip on the pulleys. In some cases two such pulleys are employed, so coupled together that as one is expanded the other is contracted, while in other cases one expanding pulley is employed, the slack

being taken by a spring-controlled jockey-pulley. In all these systems belts are employed as an expanding pulley capable of running with a chain is not yet a commercial proposition.

Friction Gearing.—A common form of frictional drive mechanism —Fig. 17 (Appendix, page 823)—consists of two friction disks arranged at right angles to one another, so that the periphery of one engages the face of the other, the relative positions of the axis of one and the path of rotation of the other being capable of being varied. An interesting modification of this type of gearing is the Cowey—Figs. 18 and 19 (Appendix, page 824)—in which the driving and driven disks engage one another face to face.

Feed-Motion Gearing.—The most common form of variable-speed gear working on the feed-gear principle is one in which reciprocating pawls operate ratchet wheels, provision being made whereby the angle through which the pawls travel can be varied. This type of gear has not obtained any hold in automobile construction, due probably to the large number of working parts and the high speed at which the reciprocating parts must work if the size of the gear is to be kept within reasonable limits. The great defect, however, of this type of gear is that when the engine speed is slow, and especially when the torque is heavy, the driving motion is apt to become jerky. Several gears, for instance the Newman and the Barber, have passed through the experimental stage with apparent success, but the fact remains that they have not been successfully used commercially.

Hydraulic Transmission.—In hydraulic transmission there are two essential elements, a pump (driven by the prime mover) by which the working fluid is put and transmitted under pressure, and an hydraulic motor (by which motion is transmitted to the road wheels of the vehicle) driven by the pump. These two elements are suitably connected, so that by varying the output of the pump per revolution the power imparted to the road wheels can be varied as desired, as if the speed of the engine is kept constant the effect

of lowering the volume of liquid pumped is to increase its pressure in the same ratio.

The advantages claimed for hydraulic transmission are: (1) that as all the mechanism is enclosed, and works in oil under pressure, friction is reduced to a minimum, and damage is practically impossible; (2) that a change of speed can be effected without any jar or strain on the prime mover; (3) that it is extremely smooth and comparatively quiet in running; (4) that in changing gear there is no necessity to disconnect the prime mover; (5) that the gear can be adjusted to the constantly varying requirements of the prime mover without checking the momentum of the vehicle, and finally, that it is simple in action, durable, and economical in working.

The various types of hydraulic transmissions that have been introduced only differ from one another in the type of pump and motor employed and in various details of construction and control, and two of them are described in the Appendix, namely, the earliest—the Hall, Fig. 20 (page 826)—and the latest—the Compayne, Figs. 21 to 27 (pages 828–30)—which is associated with the name of Dr. Hele-Shaw. The practical advantages of the Hele-Shaw system are that the pump has a uniform and steady discharge under all pressures, that sliding friction is reduced to a minimum whereby the total efficiency of the pump is materially increased; that the rotating parts of both pump and motor are perfectly balanced; that there is no end-thrust in either the pump or the motor owing to all the forces being in the plane of rotation; that all the parts are simple, and those that require any great degree of accuracy are cylindrical; that there is a minimum of wear on any of the parts; that although high pressures are employed no packing glands are required; that, owing to the rotary form of the valve, the slip of oil past the valves is reduced to a minimum because the oil pressure does not tend to open the valve, and that the inertia forces in both pump and motor are perfectly balanced. It is claimed that a long series of tests of a pump running at 1,000 revolutions per minute show an efficiency of 73 per cent. at quarter stroke, of 80 per cent. at half stroke,

and an over-all efficiency of 90 per cent. at full stroke. The mechanical efficiency of the motor is put at 95 per cent., and this efficiency is stated to be largely due to the fact that the motor works at a considerably slower speed than the pump. The combined efficiency of the whole system from engine to road wheels, including the loss in the conducting pipes due to the viscosity of the oil, as shown by trials, averages over 70 per cent. at all speeds between 5 and 15 miles per hour. The efficiency at 8 miles per hour is 76 per cent. and at 12 miles an hour 72 per cent.

Electric Transmission.—Electric systems, or, as they are more properly designated, petrol-electric systems, owing to the prime movers employed being of the internal-combustion type, may be conveniently divided into four groups:—

(1) In which the surplus power of the engine is stored in the form of electric energy in a battery of accumulators and is given out when required to augment the power of the engine, of which the Pieper or Auto-Mixte may be taken as an example.

(2) In which the entire power of the engine is converted into electrical energy, which is absorbed continuously by an electric motor driving the road wheels of the vehicle, of which the Stevens may be taken as an example.

(3) In which electric energy is employed to start and accelerate the vehicle, after which the drive from the engine to the road wheels is transmitted through a magnetic clutch, of which the Germain may be taken as an example.

(4) In which the electric energy is wholly or partially employed to start and accelerate the vehicle, after which the electric drive is cut out and the power is transmitted from the road wheels mechanically, of which the Thomas may be taken as an example.

Details of these four examples are given in the Appendix (pages 830–5). Many more or less divergent forms and combinations of these systems have been adopted by various investigators, but they differ only in details of construction and arrangement.

Considerable difference of opinion exists as to which of these petrol-electric systems is the best, and although it may well be

argued that each is best adapted for a particular class of work, there is no gainsaying the fact that the second system is the only one which has been used on a commercial scale for any considerable length of time. Dealing, however, with these systems in their numerical order. The points in favour of the first system are that the surplus power of the engine is being continuously stored in the form of electric energy which is available for use when the power of the engine requires to be augmented, and that the engine and dynamo run at a constant speed, which enables the former to be run to the best advantage and enables the latter to produce a current of suitable voltage to charge the accumulators at the proper rate.

The points in favour of the second system are, first, its simplicity, as the whole of the power of the engine is converted into electrical energy, which is transmitted direct to the motor driving the road wheels; secondly, the small number of its parts; and thirdly, as the speed of the engine is independent of that of the vehicle, it can be run at the speed at which it gives its maximum power and efficiency. It is claimed for the Stevens transmission that the over-all commercial efficiency running in normal omnibus service is 79 per cent., and that this efficiency arises chiefly from the great economy both in petrol consumption and in general upkeep. The factors which make for economy in petrol consumption are the slow speed of the engine as compared with the speed of the transmission shaft, and the ability of the vehicle to free-wheel, that is, run without propulsion, for a considerable part of its running time; while the factors which make for economy in upkeep are: (1) the simplicity of the transmission in which no gear-wheels, no clutches, and no battery are employed; (2) the absence of transmission stresses due to the elasticity of the electrical drive; (3) the absence of clutching and de-clutching as obtains in mechanical gearing; and (4) the non-braking of any electrical circuits during driving. This system has been used in the Tilling-Stevens omnibuses and other public service vehicles for several years. In the London service alone these omnibuses have run over 6,000,000 miles at an estimated cost of 7·132 pence per mile; while in the running of over 3,000,000 miles on solid rubber

tyres in the London service of omnibuses an average of 20,148 miles per tyre has been obtained.

The advantages claimed for the third system as compared with the first or second systems are, first, that when the load is within the capability of the engine the drive between the engine and the road wheels is practically, though not absolutely, mechanical, at which time the electrical losses are reduced to a minimum; and secondly, that the mechanism can be used for braking purposes. Against these, however, is the serious drawback that mechanical means have to be employed from the reverse, in addition to which the double commutator adds to the complication of the control. It is also claimed for this system that as the electrical equipment is used solely, or mainly, for starting and accelerating, the equipment can be made comparatively smaller, lighter, and cheaper; but this would seem to be a fallacy, as the output of the electrical equipment cannot be confined to starting and accelerating duties only, for the simple reason that occasions must arise when more power than can be obtained on the direct drive will be called for, thus making it necessary to use the electric transmission. As this is the most severe duty that the electrical equipment can be called upon to perform, it must be of such proportions as will propel the vehicle during the whole working period without over-heating if trouble is to be avoided.

As regards the fourth system, this is considered more economical than a direct electrical transmission, but against this must be set off the complications which arise from the introduction of the planetary gear and the clutches. The Thomas transmission has undergone two trials under the auspices of the Royal Automobile Club. The first trial was with a 36 h.p. Leyland lorry over a distance of 2,008 miles, the running being continuous day and night. The weight of the lorry unladen was 4·502 tons, and the weight of the load, including passengers, 3·181 tons, making a total of 7·683 tons. The running speed was not to exceed 12 miles per hour, and averaged (running time only) 10·47 miles per hour; the fuel consumption worked out at 7·555 miles per gallon, giving 58·046 ton-miles per gallon calculated on the gross weight and

24·030 miles per gallon calculated on the net load. During the trial no work was done upon the transmission with the exception of lubrication, for which $5\frac{1}{2}$ oz. of oil were used, and at the end of the trial the whole of the transmission, with the exception that the teeth of the double helical planetary wheels were somewhat worn, and two brushes, four sparking tips, and one brush contact point were sufficiently burnt to require renewing, was in good condition. The second trial was with a 12–16 h.p. Delahaye car from London to Edinburgh and back, in which test the fuel consumption was approximately 35 miles to the gallon, giving 67·9 ton-miles per gallon. An omnibus fitted with this transmission and running in a regular service in London has given from $10\frac{1}{2}$–11 miles per gallon of fuel. It would therefore seem that the claim that this system is more economical than the direct electrical system is well founded.

Petrol-electric systems are without doubt handicapped as compared with the sliding type of change-speed gears—at all events for use in pleasure and light commercial vehicles—first on account of excessive weight, and secondly on account of lack of power of rapid acceleration. As regards weight, it does not appear possible to make this compare favourably with the mechanical types of variable gearing without seriously risking its efficiency and even breakdown under severe duty. With respect to acceleration, it must be borne in mind that sudden acceleration of the engine—which in a purely mechanical transmission is at once transmitted to the road wheels—only results, in a petrol-electric system, in an increased generation of electricity in the dynamo, which is followed later by increased speed of the electric motor as the magnetic flux is built up in the generator, and therefore an appreciable time elapses before the current has had time to make its influence felt at the road wheels. For heavy commercial work neither the increased weight nor the sluggishness in acceleration is a matter of much serious moment, and the latter defect may even be a blessing in disguise, as it affords a means of cushioning any shocks that may be set up in the transmission system by unskilful or careless driving. As petrol-electric systems allow of maximum acceleration without subjecting any part of the vehicle to undue

strain, they have, as compared with mechanical gears, the great advantage that it places the most incompetent driver on a par with the most experienced and careful driver using a mechanical gear, and it is questionable whether—at all events for commercial work —the inability to accelerate rapidly is not more than compensated for by the saving in wear and tear arising from absence of shocks and undue strain.

Comparing petrol-electric transmission with hydraulic transmission, there does not seem to be much between them on the score of being noiseless, of not being affected by the distortion of the frame of the vehicle, and of giving a smooth acceleration and retardation. Theoretically, each seems to be an ideal transmission for motor road-vehicles, and if this Paper serves no other purpose it should at all events produce a discussion amongst the upholders of these two systems as to their relative merits, and it is not difficult to forecast that the upholders of these two systems will not be allowed to have it all their own way by the upholders of the sliding and epicyclic types of wheel gearing.

Neither the total losses on transmission nor the losses through the variable-speed gear alone under road conditions are accurately known, and will not be until some means is devised by which the actual power given out by the engine at any moment under and during running conditions can be accurately ascertained. From hill-climbing trials of cars, whose maximum engine-power is known, the total losses in transmission have been estimated to vary from 20 to 50 per cent.

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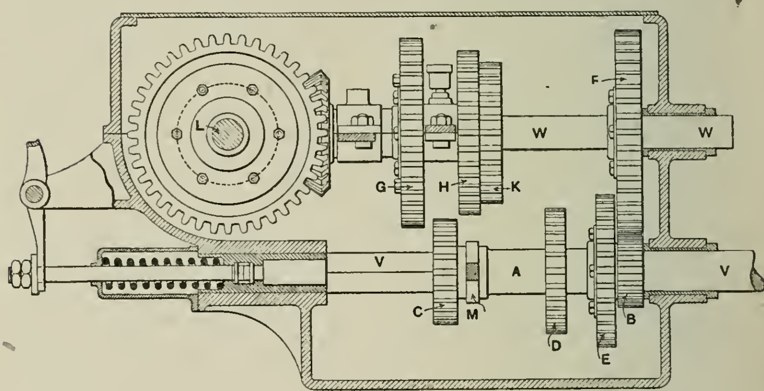
The Paper is accompanied by an Appendix, illustrated with 28 Figs. in the letterpress.

APPENDIX.

PANHARD GEAR.

In the early Panhard gear, Fig. 1, the primary or driving shaft V—capable of being coupled to the crank-shaft of the motor by means of a friction clutch —and the secondary or driven shaft W are arranged in parallel relation to one another, the secondary or driven shaft being located above the primary or

FIG. 1.—*Diagram of Panhard Gear.*



driving shaft. On the shaft V is mounted a sliding sleeve A, which carries four spur-wheels, B, C, D, and E, and on the shaft W are fixed four spur-wheels, F, G, H, and K, with which the sliding wheels B, C, D, and E can be brought into engagement one by one. In the illustration the wheel B is shown in engagement with the wheel F, which gives the first or low speed. On moving the sleeve A to the left, the wheel B is disengaged from the wheel F and the wheel C is brought into engagement with the wheel G, which gives the second speed. Further movement to the left of the sleeve A brings first the wheel D into mesh with the wheel K, thus giving the third and fourth (or highest) speeds respectively. Motion is transmitted from the driven shaft W to a transversely arranged differential shaft L by bevel-gearing, the motion of the shaft L being transmitted to the road wheels through chain-gearing. Two bevel-wheels are mounted on the shaft L, each of which is in permanent

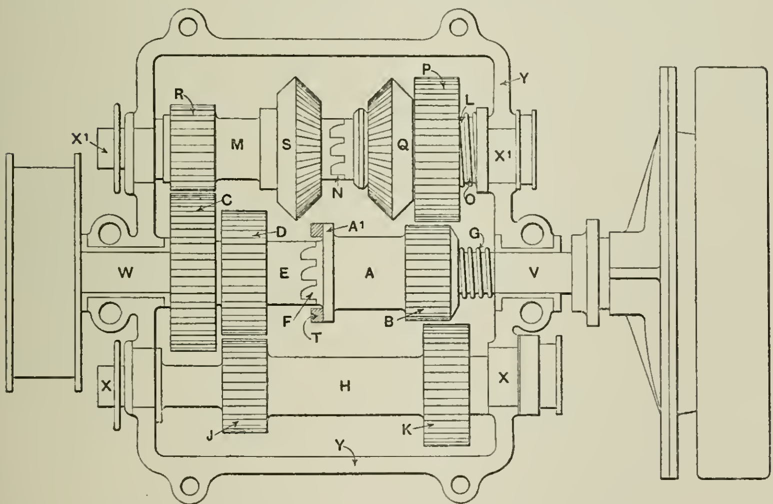
gear with the bevel-wheel on the driven shaft W, a sliding clutch being provided for coupling one or other of the two bevel-wheels to the shaft L for producing a drive either forwards or backwards.

The necessary motion is imparted to the sliding sleeve A by means of a fork M, which engages a groove in the sleeve A, this fork being operated by a pivoted hand-lever through suitable connexions, the lever being capable of being locked in the requisite positions to keep the various trains of wheels in engagement by trigger mechanism engaging with slots in a suitable quadrant.

Renault Gear.

In this gear, Fig. 2, the primary or driving shaft and the secondary or driven shaft are arranged in axial alignment, and a claw-coupling is provided

Fig. 2.—*Diagram of Renault Gear.*



between these shafts so that a direct drive, that is, not through any gearing, can be obtained. The various trains of wheels to effect the gear reductions are brought into mesh by an eccentric movement of the lay or countershafts after the manner of the back-gear of a lathe. On the driving shaft V is mounted a sliding sleeve A, which carries a spur-pinion B, and on the driven shaft W are fixed two spur-pinions C and D, the latter of which has a sleeve E with which the sleeve A engages by means of a claw-clutch F, which is kept in engagement by the spring G and which is uncoupled by imparting a sliding movement to the sleeve A against the action of the spring G by means

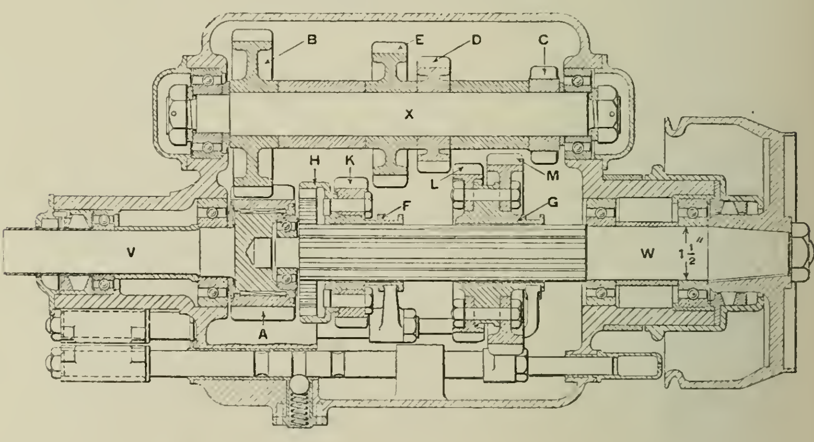
of a fork T, which engages a flange A^1 on the sleeve A. Located one on each side of the driving and driven shafts V and W are two countershafts X and X^1, which are eccentrically mounted in suitable bearings in the casing Y. On the countershaft X is mounted a sleeve H carrying two spur-pinions J and K, and on the countershaft X^1 are mounted two sleeves L and M, which are coupled together by a claw-clutch N which is kept in engagement by the spring O. The sleeve L carries a spur-pinion P and bevel-pinion Q, and the other sleeve M carries a spur-pinion R and bevel-pinion S. On rotating one or other of the countershafts X or X^1 in a similar manner to the back-gear of a lathe after the clutch F has been disengaged, either the pinions J and K can be meshed with the pinions B and D, or the pinions P and R can be meshed with the pinions B and C, thus giving the first or second speeds.

The third or top speed, which is a direct drive, is obtained when the pinions on the countershafts are out of engagement with those on the driving and driven shafts and the clutch F is re-engaged. The reverse is obtained by separating the bevel-pinions Q and S by means of a wedge action and introducing a third bevel-pinion to mesh with these bevel-pinions, at the same time uncoupling the clutch F and throwing the pinions P and R into engagement with the pinions B and C.

Modern Daimler Gear.

In this gear, Fig. 3, the front end of the driven shaft W is journalled in the rear end of the driving shaft V, on which is fixed the permanent driving spur-pinion A, which is in constant mesh with a spur-pinion B on the

FIG. 3.—*Modern Daimler Gear.*



countershaft X. This countershaft also carries other spur-pinions C, D and E. The driven shaft W is splined, and on it are mounted two sliding sleeves F and G, the former carrying both an internally toothed wheel H and a spur-pinion K. The internally toothed wheel H by engaging with the pinion A forms a direct driving couple between the driving shaft V and the driven shaft W, and gives the fourth or top speed, and the spur-pinion K by engaging with the pinion E on the countershaft forms the driving connexion between the countershaft and the driven shaft to give the third speed. The sleeve G also carries two spur-pinions L and M, the former adapted to mesh with the pinion D on the countershaft to give the second speed, and the latter adapted to mesh with the pinion C on the countershaft to give the first or lowest speed.

Mercedes Control.

In this control, Figs. 4, 5, and 6, a shaft A is so mounted as to be capable of having both a fore and aft rocking movement and a transverse

Fig. 4.

Diagram of Mercedes Control.

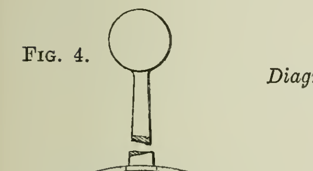
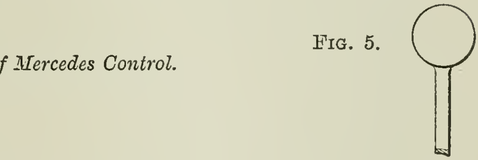


Fig. 5.



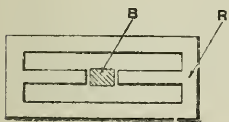


Fig. 6.

sliding movement imparted to it by the hand-lever B. This shaft carries a selector arm C which terminates in a fork D, one element of which engages one or other of the rods E and F through a toothed quadrant H and a rack R, and the other element of which engages a slot K in a locking key or bolt L through a plain quadrant M. The rods E and F, which engage the sliding elements of the gear by means of the usual forks, are mounted to slide in a suitable guide N, in which the locking key or bolt L is mounted and arranged to slide. The plain quadrant M, by reason of its permanent engagement with the slot K in the key or bolt L, is free to move in respect of this key or bolt when the shaft A is rocked, and to impart a corresponding relative movement to this key or bolt when the shaft A is moved axially. In the underside of each of the rods E and F is a slot O with which the key or bolt L engages, and in this key or bolt is a second slot P, which will allow either of the rods E or F to pass across it when they are brought into line with it by the transverse movement of the selector arm C. It will be seen that, by imparting an axial movement to the shaft A, the toothed quadrant can be moved out of its central position—in which it can have no rocking movement by reason of its engagement with the central bar of the "gate" guide—and can be engaged with one or other of the controlling rods E and F, at which time the slot P in the key or bolt L is so positioned as to allow the rod with which the toothed quadrant is engaged to slide in its bearing—through the key L—on motion being imparted to it by the toothed quadrant H by reason of the rocking motion imparted to the shaft A. The gate R for this mechanism is illustrated in Fig. 6, the hand-lever B being shown in its central position, in which position as shown in Fig. 5 the toothed quadrant H is out of engagement with either of the rods E and F, and these rods are positively locked against movement by the key or bolt L. If the hand-lever is moved into one or other of the slots of the gate, the selector arm becomes engaged with one or other of the controlling rods, and on a fore or aft movement being imparted to the hand-lever, the sliding sleeve in the gear-box is moved in one or other direction to engage one or other of two trains of wheels. When there are four speeds and a reverse, the two sliding elements give the top and third speeds and the second and first speeds respectively, and the reverse is obtained either by means of a separate sliding element with an independent pick-up, or by running through the first speed.

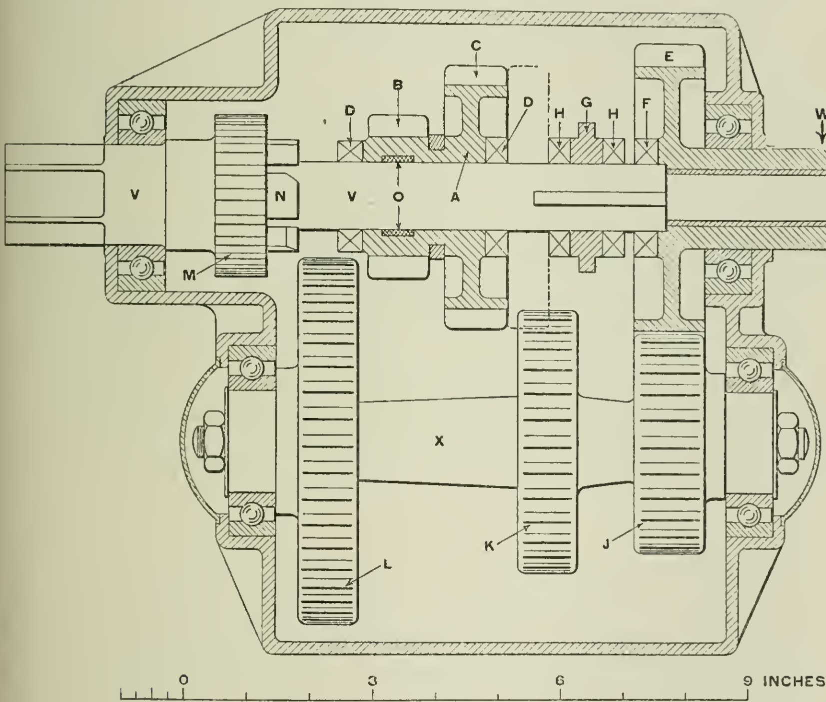
Instead of using a positive lock for the controlling rods, automatic spring-controlled catches are often employed. A common form is a small sphere held up by a spring and adapted to engage with grooves turned in the controlling rod. Such a device is shown in the illustration of the Daimler gear-box, Fig. 3. The most up-to-date practice is to mount the gear-changing mechanism on the gear-box instead of on the frame of the vehicle, so as to

avoid the possibility of any binding taking place due to distortion of the frame.

Weller Gear.

In this gear, Fig. 7, a sleeve A carrying two spur-pinions B and C, and having claws D at each end, is mounted on the driving shaft V so that it is free both

Fig. 7.—*Weller Gear.*



to slide and rotate thereon. On the driven shaft W, which is hollow and fits over the end of the driving shaft, is fixed a spur-pinion E having claws F on its inner side. On the shaft V is also mounted a sleeve G, which is free to slide thereon, but which has no independent rotary movement. This sleeve is provided with claws H at each end whereby it can be coupled either to the sleeve A carrying the spur-pinions B and C by means of the claws D and H, or to the spur-pinion E on the driven shaft by means of the claws F and H. On the countershaft X are fixed three spur-pinions J, K, and L, the former of

which is in constant mesh with the pinion E on the driven shaft. On the driving shaft is a fixed spur-pinion M for the reverse which is provided on its end opposite the sleeve A with claws N adapted to engage with the claws D on the adjacent end of the sleeve. If the sleeve G is moved to the right until it engages the spur-pinion E, the driven shaft is coupled to the driving shaft, thereby giving a direct through drive, which is the top gear. If the sliding sleeve A is moved to the right after the sleeve G has been withdrawn from engagement with the pinion E, the pinion C first becomes meshed with the pinion K on the countershaft, and subsequently becomes engaged with the sleeve G, the effect of which is to couple the pinion C to the driving shaft and give the second speed through the wheels C, K, J, and E. The dot-and-dash line shows how the pinion C is engaged with the pinion K before it engages the sleeve G, thus ensuring the safety of the teeth of the pinions at the moment of the couple of the pinion C with the driving shaft. If the sleeve A is moved to the left the pinion B first engages the pinion L on the countershaft, and subsequently becomes coupled to the driving shaft by the engagement of the sleeve A with the pinion M. Within the boss of the sleeve A is a friction ring O, the function of which is to cause the sleeve to rotate with the shaft when the sleeve is in its central or free position, whereby the wear between the sleeve and the shaft is reduced to a minimum, as the only movement between these two parts is at the moment of engagement of the first and second speed trains. The reverse is obtained by bringing an intermediate pinion mounted on an independent shaft—not shown in the illustration—into engagement with both the pinion M and the pinion L when the sleeve A is in its central or free position.

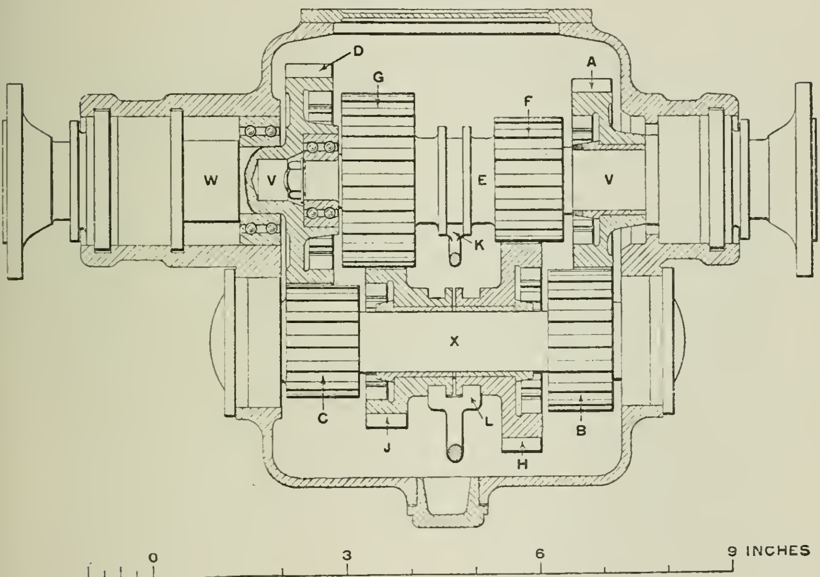
DUX GEAR.

In this gear, Fig. 8, a spur-pinion A is so mounted on the driving shaft V as to have free relative rotary movement thereon, and is in constant mesh with a spur-pinion B, fixed on one end of the countershaft X. On the other end of the countershaft is fixed a spur-pinion C, which is in constant mesh with a spur-pinion D, fixed on the driven shaft W. On the driving shaft, which is splined to receive it, is a sliding sleeve E, which carries two spur-pinions F and G, and on the countershaft are, loosely mounted, two spur-pinions H and J, the former of which is in constant mesh with the pinion F, and the latter in constant mesh with the pinion G. Each of the pinions A and D has an internal ring of teeth with which the teeth of the pinions F and G respectively engage when the sleeve E is moved to the right or left, and each of the pinions H and J has an internal ring of teeth which engages with the teeth of the pinions B and C respectively when the pinions are moved to the right or to the left. Motion is imparted to the sleeve E by means of the usual

fork K, and motion is imparted to the two pinions H and J by a fork L, which engages the bosses of both of these pinions, so that, although the pinions have free relative rotary movement, they are constrained to move together axially.

The top or direct drive is obtained by engaging the pinion G with the internal teeth of the pinion D, thereby locking the driving shaft to the driven shaft. The third speed is obtained by sliding the sleeve E until the pinion F engages the internal teeth of the pinion A, so that the drive is transmitted

Fig. 8.—*Dux Gear.*



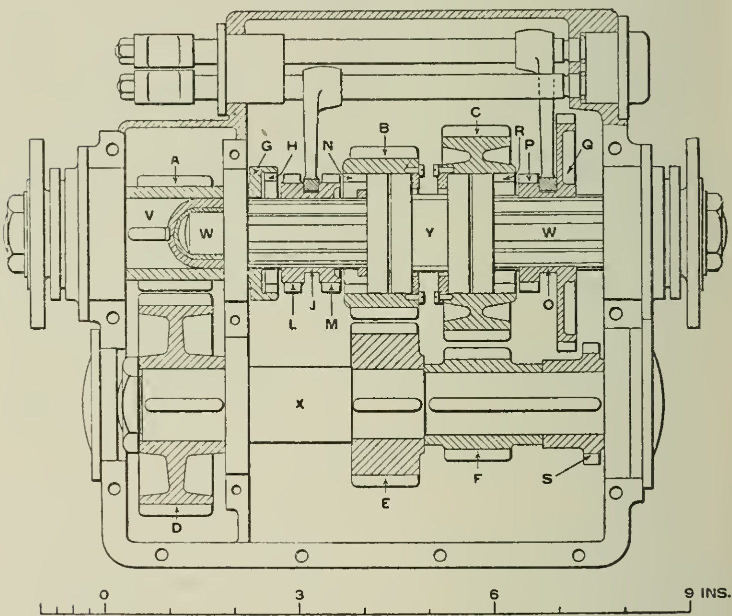
through F–A, B, C, and D. The second speed is obtained by sliding the two pinions H and J until the internal teeth of the pinion J engage the pinion C, so that the drive is transmitted through G, J, C, and D. The first speed is obtained by sliding the pinions H and J until the internal teeth of the pinion H engage the pinion B, so that the drive is transmitted through F, H–B, C, and D. The reverse is obtained by sliding a double gear—not shown in the illustration—into mesh with the pinions D and H.

Chain Gear Box.

This box, Fig. 9, gives three forward speeds and a reverse, the forward speeds, other than the direct drive, being produced by sprocket-wheels and chains,

and the reverse by spur-wheels. On the driving shaft V is fixed a sprocket-wheel A, and on the driven shaft W are two loosely mounted sprocket-wheels B and C. On the countershaft X are fixed three sprocket-wheels D, E, and F. On the inner end of the driving shaft, which forms the spigot for the inner end of the driven shaft, is a collar G, having internal teeth H, which forms part of a claw-clutch. Between this collar G and the sprocket-wheel B is a sliding sleeve J, which carries two rows of teeth L and M forming parts of claw-clutches. The sprocket-wheels A and D, B and E, and C and F are

FIG. 9.—*Chain Gear-Box.*



coupled by means of chains of the Coventry "noiseless" inverted-tooth type. By moving the sleeve J to the left, the teeth L engage the teeth H, whereby the driven shaft is coupled to the driving shaft, which gives the direct and top drive. By sliding the sleeve J to the right, the teeth M engage an internal row of teeth N carried by the sprocket-wheel B, whereby the sprocket-wheel is coupled to the driven shaft, which gives the second speed through the wheels A, D, E, and B. On the driven shaft beyond the sprocket-wheel C is a sliding sleeve O, on one end of which are teeth P and on the other end of which is a spur-wheel Q. By moving the sleeve O to the left, the teeth P

engage an internal row of teeth R on the sprocket-wheel C, whereby the latter is coupled to the driven shaft, which gives the first speed through the wheels A, D, F, and C. By moving the sleeve O to the right, the spur-wheel Q is brought into mesh with a spur-pinion S on the countershaft, whereby the reverse is obtained through the wheels A, D, S, and Q. It will be seen that, as when two shafts are coupled together by chain and sprocket-wheel gearing they both rotate in the same direction, the reverse can be obtained by the use of two spur-wheels only without the use of an intermediate wheel.

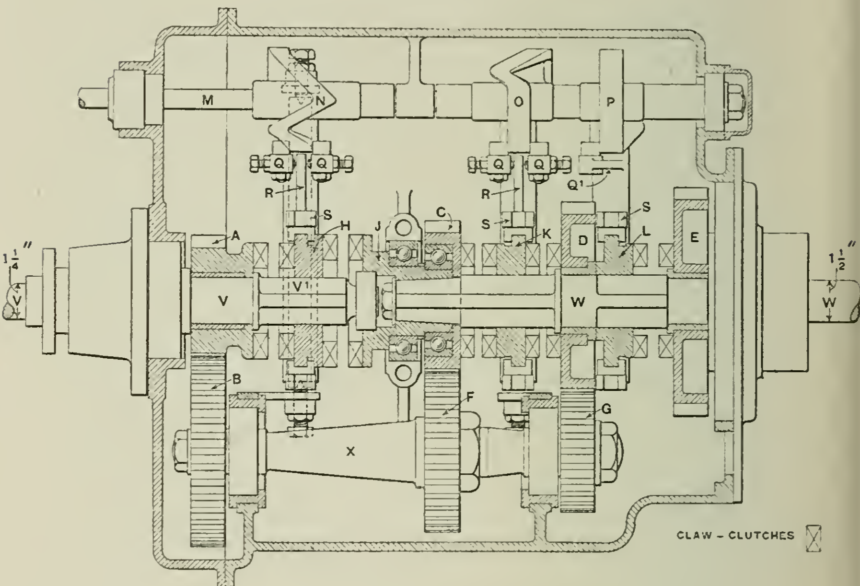
Linley Automatic Control.

In this control, Fig. 10, a spur-pinion A is loosely mounted on the driving shaft V—which is arranged in axial alignment with the driven shaft W—and is constantly in mesh with a spur-pinion B fixed on the countershaft X. On the driven shaft are loosely mounted three spur-pinions C, D, and E, each of which is provided on one side with claw-teeth, and two of which, C and D, are respectively constantly in mesh with pinions F and G on the countershaft. Mounted on the squared end V^1 of the driving shaft V is a sliding double claw-clutch H, which, if moved to the left, engages with teeth carried by the pinion A, thereby locking the pinion to the driving shaft; and if moved to the right engages with teeth carried by a collar J fixed on the driven shaft and forms the spigot for supporting the bearing for the inner end of the driving shaft, thereby locking the driving shaft direct to the driven shaft and producing the direct drive and top speed. On the squared parts of the driven shaft between the wheels C and D and D and E are mounted two other sliding claw-clutches K and L, the former of which, if moved to the left, couples the pinion C to the driven shaft for producing the second speed, and if moved to the right couples the pinion D to the driven shaft for producing the first speed. The other clutch L, if moved to the right, locks the pinion E to the driven shaft for producing the reverse through an intermediate pinion—not shown—which gears with both E and G. Mounted parallel with the driving and driven shafts is a cam-shaft M, which is rotated by the operation of the change-speed lever through suitable mechanism. This shaft carries three cams, N, O, and P. With each of the cams N and O two rollers, carried by two spring-controlled levers Q, of the fly-to-centre type, engage, and with the cam P one spring-controlled lever Q^1 engages. The springs controlling these levers are not shown in the illustration for the sake of distinctness. Between each of the pair of levers Q is an arm R, forming part of the swinging fork S, by means of which each of the sliding clutches H and K is shifted, and the lever Q^1 is carried by a sleeve which carries the swinging fork S by which the sliding clutch L is shifted.

When the change-speed lever is in its neutral position the peripheries of

the cams are all parallel so that the fly-to-centre levers are lying dormant and the clutches are all disengaged. The claws of the clutches and the parts with which they engage are undercut so that they remain in engagement even against the pressure of the spring of the fly-to-centre levers so long as a driving pressure is on them, but when this pressure is released, either by de-clutching the engine or by throttling the engine down so as to remove the driving effort temporarily, the spring operates to cause one of the clutches to

FIG. 10.—*Linley Automatic Control.*



become operative either alone or at the same time that the other clutch becomes inoperative.

The operation of changing speed is as follows: when the change-speed lever is brought from the neutral notch into the first speed notch, it rotates the cam-shaft for about one-fifth of a turn. This causes the cam N to throw over one of the pair of fly-to-centre levers Q, thereby putting tension on the spring which controls these levers, with the result that the moment that the claws of the clutch H come opposite to those of the pinion A the spring acting through the arm R causes them to engage automatically, thereby locking the pinion A to the driving shaft. At the same time the movement of the second cam O has performed a corresponding operation on the pair of

fly-to-centre levers Q controlling the clutch K, and the spring acting through the arm R causes this clutch to engage with the first-speed pinion D, thereby locking it to the driven shaft and completing the train A, B, G, and D for producing the first speed.

When the change-speed lever is moved into the second-speed notch, which operates to rotate the cam-shaft through a further part of its revolution, no further motion is communicated to the levers Q controlling the clutch H, so that the clutch remains engaged with the pinion A. The second cam O, however, operates to transfer the tension of the spring of the pair of fly-to-centre levers controlling the clutch K in the opposite direction, so that when the driving strain is released, the spring operates through the arm R to throw the clutch K out of engagement with the first-speed pinion D and into engagement with the second-speed pinion C.

On putting the change-speed lever into the third-speed notch, the cam-shaft is again partially rotated, which causes the cam O to operate to put tension on the spring of the pair of fly-to-centre levers Q controlling the clutch K, so that when the driving strain is released, the spring operates through the arm R to draw the clutch K out of engagement with the pinion C, and causes the cam N at the same time to operate to transfer the tension of the spring of the fly-to-centre levers Q controlling the clutch H in the opposite direction, so that, when the driving strain is released, this spring operates through the arm R to throw the clutch H out of engagement with the pinion A and into engagement with the claws of the collar J on the driven shaft, thus coupling the driving and driven shafts together and giving the third or top speed with a direct drive.

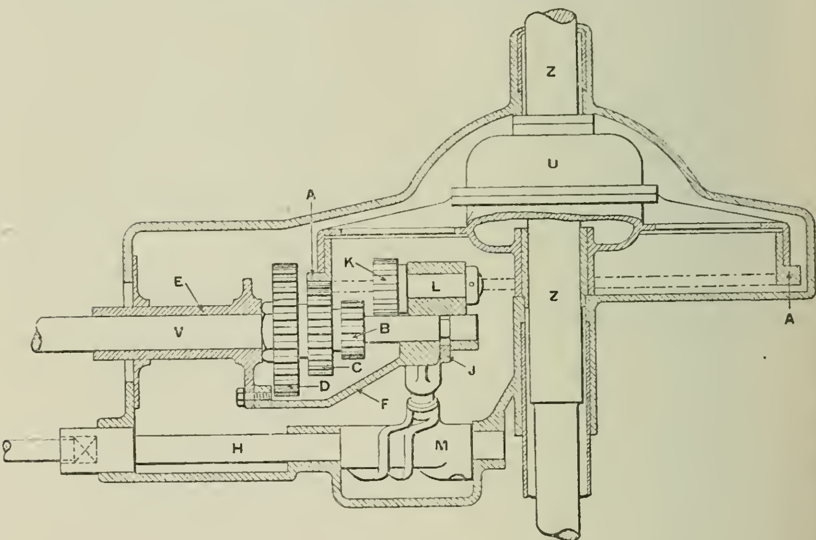
To obtain the reverse, the change-speed lever is moved into the reverse notch, which causes the cam N to operate to engage the clutch H with the pinion A, and at the same time causes the cam P to operate to allow the clutch L to be pulled over—by a spring not shown in the illustration—to engage with the reverse pinion E which is driven from the pinion G on the countershaft through an intermediate pinion, which is also not shown.

It will be seen that the reason that the gear does not change immediately on pulling over the change-speed lever is that the clutches cannot disengage themselves while under load. The pulling over of the lever simply compresses a spring which cannot move the clutches owing to the pressure on their engaging claws. When this pressure is removed by de-clutching or by releasing the driving effort, the spring which has been compressed asserts itself and changes the gear. The gear changing can only be automatically effected when the engine is actually driving the car, so that if it becomes necessary to change the gear when the car is over-running the engine, it must be effected in the usual way, namely, by de-clutching before actuating the change-speed lever.

Sizaire-Naudin Gear.

In this gear, Fig. 11, a crown-wheel A is mounted on the differential casing U of the live back-axle Z, and on an extension V of the propeller-shaft are three spur-pinions B, C, and D, which give the three forward speeds by engagement with the crown-wheel A. The driving shaft V is mounted in bearings E carried by a frame F, which is so mounted on a longitudinally arranged shaft located under the back end of the driving shaft—not visible in the illustration, which is a view in plan—that it is free to rock transversely and move

Fig. 11.—*Diagram of Sizaire-Naudin Gear.*



longitudinally in relation to the crown-wheel A, for the purpose of bringing one or other of the spur-pinions B, C, and D into engagement with the wheel, the driving shaft being so connected to the propeller-shaft of the engine as to allow of the required longitudinal movement, and the usual universal joint at the front end of the propeller-shaft allowing the transverse movement. On a shaft H, located at the side of the driving shaft, is a grooved cam M, which is so shaped that rotation of the shaft produces the necessary compound rocking and sliding movement of the frame F to bring the pinions B, C, and D successively into engagement with the crown-wheel A.

To produce the reverse, the driving shaft is moved longitudinally in relation to the frame E by means of an independent fork J to bring the first-

speed pinion B into mesh with a pinion K mounted on an independent shaft L, after which the frame E is moved by the action of the shaft H and the cam M to bring the pinion K into mesh with the crown-wheel A, its intermediate position between the spur-wheel B and the crown-wheel A giving the reverse motion to the crown wheel.

Humphris Gear.

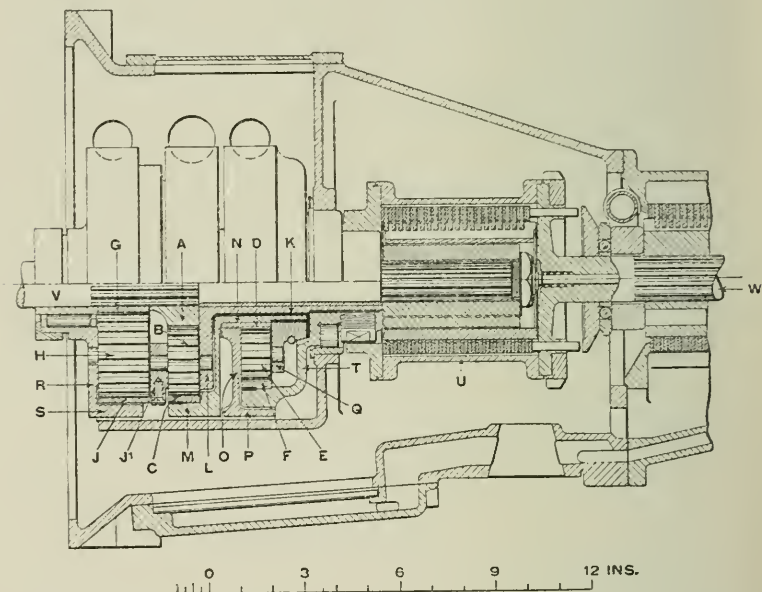
A gear of a similar nature is the Humphris gear, which consists of a pinion—having hemispherical teeth—mounted on the end of the propeller-shaft which gears with one or other of a series of countersunk holes or hemispherical recesses in the face of a disk mounted on the differential gear-box of the axle to be driven. Each of the concentric rows of holes or recesses represents a different gear ratio, the slowest speed being obtained when the pinion on the propeller-shaft is in engagement with the outer row of holes or recesses in the driving disk, and the highest gear when the pinion is in engagement with the innermost row of holes or recesses. The end of the propeller-shaft is so mounted that it can be moved transversely within certain limits, for the purpose of bringing the pinion in and out of engagement with the driving disk. To change the gear, the end of the propeller-shaft is swung over to disengage the pinion, after which the pinion is moved longitudinally on its shaft to bring it into position to engage the particular row of holes or recesses in the driving disk which will give the desired speed. The propeller-shaft is then swung back to bring the pinion into engagement with the disk. It is claimed for this gear that there is no side thrust and that it has an efficiency of 85 per cent.

Lanchester Gear.

In this gear, Fig. 12, there are three epicyclic trains, the sun-wheel, planet-wheels, and annulus of which are denoted by A, B, and C; D, E, and F; and G, H, and J respectively, the first train giving the first or lowest speed, the second—in combination with the first—the second speed, and the third the reverse. The third or highest speed is obtained by locking the gears together by the action of a clutch which, as shown, is of the multi-plate type. The essential feature of this gear is the compounding of two trains to produce the second or intermediate speed, the interaction being obtained from the driven element. The sun-wheels A and G of the first and third trains respectively are fixed on the driving shaft V, which is a continuation of the crank-shaft of the engine. The driving shaft also carries the inner or male parts of the friction clutch, the female or outer parts of said clutch being carried by a casing U, which is in permanent couple with the driven shaft W.

Coupled with the casing U is a sleeve K, which is loosely mounted on the driving shaft V and carries a carrier L for the planet pinions B of the first train, this carrier, therefore, being in permanent direct couple with the driven shaft. The annulus C of this train is carried by a sleeve N, which is loosely mounted on the sleeve K and carries a brake-drum M. The sun-wheel D of the second train is fixed on the boss of a disk O, which is loosely mounted on the sleeve N and carries a brake-drum P. The planet-wheels E of the second train are carried by a carrier Q, which is fixed to the sleeve N,

FIG. 12.—*Lanchester Gear.*



and therefore in permanent direct couple with the annulus C of the first train. The annulus F of the second train is carried by a disk T, which is fixed on the sleeve K, and is therefore in permanent direct couple both with the carrier L of the first train and also with the driven shaft through the casing U of the clutch, the couple between the sleeve K and the casing U being by means of a dog-key carried by the boss of the disk T and engaging a recess in the boss of the inner flange of the casing U. The planet-wheels H of the third train are carried by a carrier R, which is loosely mounted on the driving shaft V and carries a brake-drum S, and the annulus J of this train is mounted on a disk J^1, which is fixed to the carrier L of the first train, and is therefore in

permanent direct couple with the driven shaft. It will be seen that the sun-wheel A, the sun-wheel G, and the inner or male part of the clutch are all coupled to the driving shaft, and therefore revolve at the same speed. Also that the outer or female part of the clutch and the sleeve K, and therefore the pinion carrier L, are coupled to the driven shaft.

To obtain the lowest speed, the drum M is held stationary, and as the

FIGS. 13 TO 16.—*Diagrams of Lanchester Gear.*

FIG. 13.

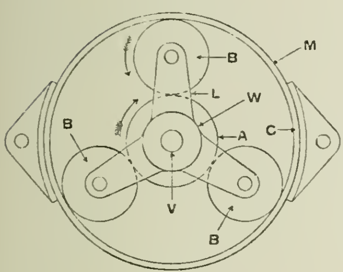


FIG. 14.

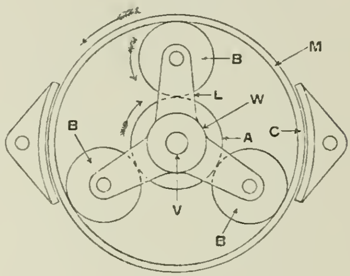


FIG. 15.

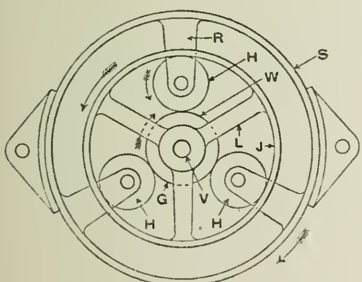
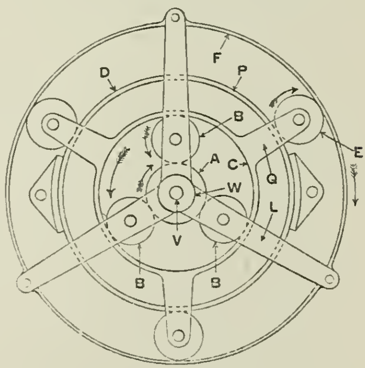


FIG. 16.



sun-wheel A is driven by the engine the carrier L, and with it the pinions B, is caused to rotate as a whole in the same direction as the sun-wheel, but at a lower speed. This is the ordinary form of epicyclic gear, and is shown diagrammatically in Figs. 13 and 14, the former showing the gear in action and the latter running idle.

To obtain the second speed both the train A, B, and C and the train D, E, and F are employed. The combined action of these two trains can best be

followed by bearing in mind that the end to be attained is a speed intermediate between the highest speed, which is obtained by locking all the elements of the epicyclic trains together by means of the clutch, and the lowest speed, which is obtained as before described. This is effected by causing the carrier L of the first train to move faster, which end is attained by causing the pinion carrier Q of the second train, which is coupled to the annulus C of the first train, to revolve in the same direction as the carrier L by holding the sun-wheel D of the second train stationary by means of the drum P. This causes the carrier Q, and with it the annulus C, to rotate in the same direction as the sun-wheel A, which thus augments the speed imparted to the carrier L, and therefore the speed imparted to the driven shaft. The action of this compound gear is shown diagrammatically in Fig. 16, the elements D and F being enlarged to allow them to be shown concentric with but clear of the elements A, B, and C.

To obtain the highest speed—a direct drive—the clutch is brought into action which locks all the parts of the gear together, so that they revolve *en masse*. At all the other speeds the clutch is out of action.

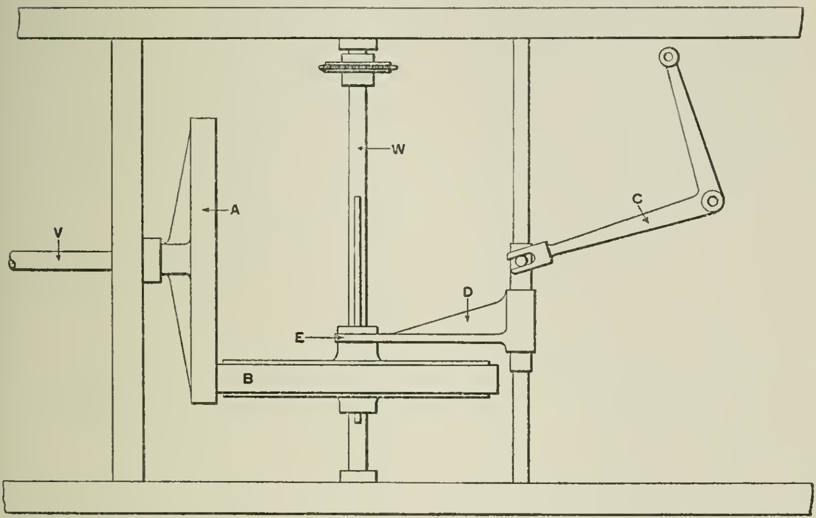
To obtain the reverse, the drum S to which the planet carrier R is fixed is held stationary, so that the annulus J, and with it the carrier L, and therefore the driven shaft, will be rotated in a reverse and opposite direction to the driving shaft by the action of the intermediate pinions H. The action of this gear is shown diagrammatically in Fig. 15.

Common Form of Friction Gear.

In this gear, Fig. 17, the driving disk A is mounted on a shaft V, which is in couple with the crank-shaft of the engine, and the driven disk B is mounted on a shaft W, which is arranged at right angles to the axis of the driving shaft V and is in couple with the driving road-wheels by means of chain and sprocket-wheel or other gearing. The driven disk B is so mounted to slide on its shaft that it can be moved across the face of the driving disk A, and thus by engaging the disk at any desired position between its centre and its periphery enable any desired speed ratio to be obtained. Provision is made for drawing the driving disk A out of engagement with the driven disk B before it is moved transversely to alter the gear ratio, the driving disk A being kept up to its work—that is, in frictional driving contact with the disk B by means of suitably arranged spring-pressure.

The reverse is obtained by bringing the driven disk B over to the other side of the driving disk A, and it is usual in this form of gear to recess the driving disk in the centre so as to provide a neutral point in which motion is not imparted to the driven disk. The driving contact between the two disks is broken by drawing the driving disk A back out of engagement with the

Fig. 17.—*Diagram of Common Form of Friction Gear.*



driven disk B, which is usually effected by means of a foot-pedal operating similarly to a clutch-pedal, and the position of the one disk in relation to the other is varied and determined by means of a hand-lever working over a notched bar or quadrant and in couple with the sliding driven disk B through the bell-crank lever C and a sliding element D, which carries a fork E that engages a groove in the boss of the sliding disk.

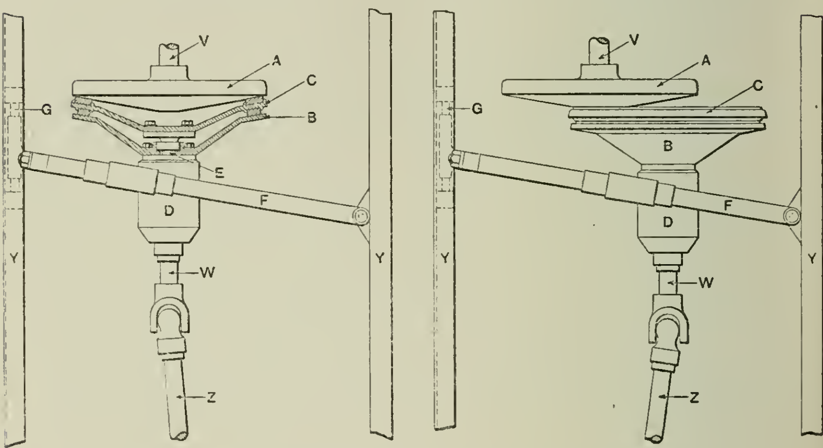
Cowey Friction Gear.

In this gear, Figs. 18 and 19, the driving and the driven disks engage one another face to face. The former shows the disposition of the parts when the engine is driving the transmission shaft at its highest speed, and the latter the disposition of the parts when the engine is driving the transmission shaft at a reduced speed. Between the rear face of the disk A mounted on the crank-shaft V of the engine and a disk B mounted on the driven shaft W is an intermediate disk C. The rear face of the disk A is coned, and both the disk B and the intermediate disk C are dish-shaped, the former being faced on one side and the latter on both sides with a suitable friction material such as ‘ Feredo.” The disk B is carried by the driven shaft W, the front part of which is mounted in bearings in a housing D and is hollow to receive the shaft E which carries the intermediate disk C. The rear end of the driven

shaft W is coupled to the propeller-shaft Z by the usual universal coupling. The housing D is mounted to slide on a frame F (which consists of a pair of transversely arranged superimposed bars), which is pivoted at one end to one of the side members Y of the frame of the chassis and is adapted at the other end to slide in or on a suitable guide G carried by the other member Y of the frame. Means are provided both for operating the frame F for the purpose of pulling the driven disk B out of engagement with the intermediate disk C so as to disengage the driving couple, and to move the housing D carrying

Figs. 18 and 19.—*Diagrams of Cowey Friction Gear.*

Fig. 18. Fig. 19.



the driven and intermediate disks and their shafts laterally in relation to the disk A so as to cause the intermediate disk C to engage the face of the disk at a different part of its surface.

It will be seen that when the axes of the driving shaft and of the driven shaft, and therefore of the disk A and the intermediate and driven disks C and B are co-axial, the apparatus is simply a direct-driving clutch, and that to obtain the lower speeds and the reverse it is only necessary to move the disks B and C across the face of the disk A so that the rim of the intermediate disk C will engage with a portion of the surface of the driving disk which is nearer to its centre, and obviously the nearer the driven disk is moved towards the centre of the driving disk the greater is the effective speed reduction. If the rim of the intermediate disk C is moved beyond the centre of the driving disk the direction of rotation of the driven shaft is changed, which gives the reverse drive. The housing D carrying the intermediate and driven disks C

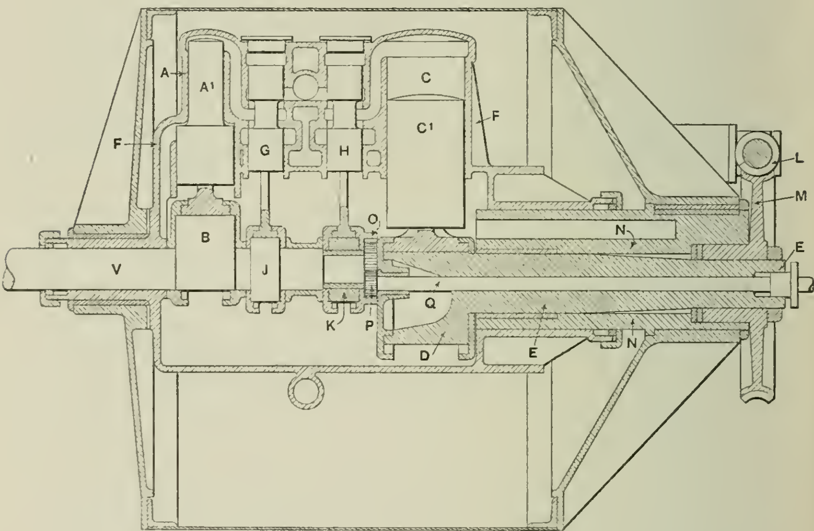
and B is coupled to the clutch-pedal, so that it can be drawn backwards sufficiently to disconnect the engine from the disks by depressing the pedal, a suitable spring being employed to return the housing and keep the disks up to their work when pressure on the clutch-pedal is removed. Within the housing D at the rear end of the shaft E carrying the intermediate disk C is a helical spring, which operates between the end of the shaft and the end of the hollow part of the driven shaft W. This spring, when the housing D is drawn back, separates the intermediate disk C from the driven disk, so that when the clutch-pedal is depressed not only is the intermediate disk separated from the driving disk but also from the driven disk, so that there is no rubbing friction whatever between these parts. The effect of the use of the intermediate disk is to provide a complete annular clutch which renders wear a negligible quantity. In this gear all the drives are direct, so that loss in transmission is reduced to a minimum and at all speeds is silent. Further, as any gear and the reverse can be easily and rapidly engaged at any engine or car speed, a valuable emergency brake is provided.

Hall Hydraulic Gear.

In the Hall transmission, Fig. 20, three radially arranged pumps A are employed, the plungers A^1 of which are operated through connecting-rods by a common crank B on the shaft V, which is driven by the prime mover. Three radially arranged motors C are also employed, the pistons C^1 of which are operated through connecting-rods by a crank D on a non-rotating shaft E, which is arranged eccentrically in relation to the driving shaft V. Both the pumps A and the motors C are carried in a common casing F, which is free to rotate about the axis of the driving shaft V and is coupled to the driving road-wheels through suitable gearing. The cylinders of each pair of pumps and motors are connected by ports controlled by valves G and H, the valves G of the pumps being operated by an eccentric J on the driving shaft V, and the valves H of the motors by an eccentric K, which is loosely mounted on and in relation to the driving shaft V and is provided with means whereby it can be rotated through a given arc. The shaft E, although non-rotating, is capable of a limited amount of rotation—through the worm L and the worm-wheel M—in order to adjust the eccentricity of the crank K. The shaft E carrying the crank D is carried in an eccentric bush or bearing N, the eccentricity of which is equal to the throw of the crank D, so that when the crank is turned so that its greatest throw coincides with the greatest eccentricity of the bush or bearing N the crank will be concentric with the shaft V, and will then act merely as a fixed axle and impart no movement to the pistons C^1 of the motors C as the casing F rotates. The eccentric K on the driving shaft V, which operates the valves H of the motors, has an extension O which is

toothed internally and engages a spur-pinion P carried on a shaft Q, which passes centrally through a hole in the shaft E. The shaft Q is provided with suitable means of rotation exterior to the casing F, so that the position of the eccentric L can be altered in relation to the crank D. By this means, in a manner similar to that of the well-known form of loose eccentric reversal employed in marine engines, the direction of rotation of the casing F can be reversed when required. The whole of the spaces, passages, and cylinders of the casing F are filled with oil, which is constantly pumped by the pumps A

Fig. 20.—*Diagram of Hall Hydraulic Gear.*



through the valves G and H to the motors C, the capacity of which exceeds that of the pumps.

The action of the apparatus is as follows: Upon motion being imparted to the driving shaft V, the pumps A operate to pump oil into the back ends of the cylinders of the motors C, which thereby impart rotary motion to the casing F, the ratio of speed between the driving shaft and the casing being determined by varying the centre of the crank operating the pistons of the motors with respect to the axis of the driving shaft. When the cylinders of the motors are working to their full capacity the greatest reduction of speed is obtained, and inversely when they are working at their lowest capacity the highest speed is obtained, the casing F then rotating at the same speed as the driving shaft V. If, as in the construction illustrated, the capacity of the

motor cylinders is four times that of the pump cylinders, when the crank of the motors is in the position to impart the greatest amount of movement to the pistons of the motors, it will take four strokes of the plungers of the pumps to fill the cylinders of the motors with oil, and consequently the shaft V will have rotated four times during the time the pumps have, by filling the motors, caused the casing F to rotate once, but, as in normal working, shaft V and the casing F rotated in the same direction, one revolution of the pump shaft is lost for each revolution of the casing, so that the shaft V is geared down in relation to the casing F in proportion of 5 to 1. As before stated, when the crank D is concentric with the shaft V there is no movement of the pistons of the motors, and consequently the whole apparatus is carried round at the same speed as the shaft V, and the highest speed of rotation is imparted to the casing F. In this condition there is no circulation of the fluid in the apparatus, and except for the connecting-rods of the motors turning upon the crank D and the rods of the valves H moving upon the eccentric, there is no relative movement of the various parts of the mechanism. It will be understood that the two positions of the crank D before described are the two extremes, and that any intermediate position of the crank and consequently variation of the proportions of speed and power of the whole apparatus can be obtained by rotating the crank D.

Compayne Hydraulic Gear.

The essential feature of the Compayne transmission is the Hele-Shaw pump, Figs. 21 and 22, which by reason of its construction can not only be run at a high speed without vibrations, but has a high degree of efficiency. The construction and action of this pump—which is of the rotary plunger type with a plurality of cylinders—will best be understood by reference to Figs. 23, 24, and 25, which are diagrammatic sections through the pump at right angles to its axis. The cylinders A (of which there are seven in the construction shown) are formed in one block with a sleeve which is mounted on a fixed stub axle B, this sleeve being coupled to a shaft S which is driven by the prime mover. The pistons C carry gudgeon-pins D, which pass through slots in the cylinders and engage with slipper pieces E which fit in two opposed grooves in a drum F, which is mounted in ball-bearings to rotate in a housing G. The grooves in the drum F form paths for the gudgeon-pins, and the drum F operates as a floating ring, the action and operation of which in relation to the pistons is that of a series of connecting-rods. The housing G is mounted to slide transversely across the casing X in suitable guides. By displacing this housing in the casing X in relation to the stub axle B on either side of its vertical centre line, that is to say, along a horizontal line *xx* passing through the centre of said axle, the eccentricity of the path of the

gudgeon-pins with respect to the cylinders can be varied for the purpose of varying the stroke of the pistons, and therefore the output of the pump as a whole. As the acceleration of the slipper-pieces and pistons above the centre line xx is balanced by the retardation of similar parts below the centre line, all the inertia forces are balanced.

The drum F is kept full of oil by centrifugal action, and no oil is allowed to accumulate in the casing X, whereby all churning of the oil is avoided. In the stub-axle B, about which the cylinder block revolves, are two ports or groups of ports, H and K, with which ports in the bases of the cylinders A coincide as they revolve, the ports being in communication with similar ports or groups of ports, H^1 and K^1, at one end of the axle B exterior to the

Figs. 21 and 22.—*Hele-Shaw Pump. Compayne Hydraulic Gear.*

Fig. 21.

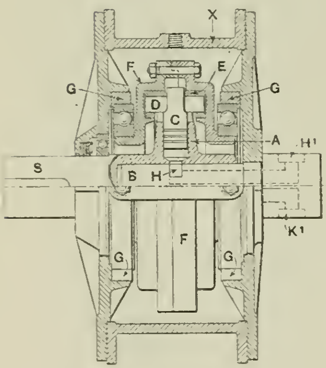
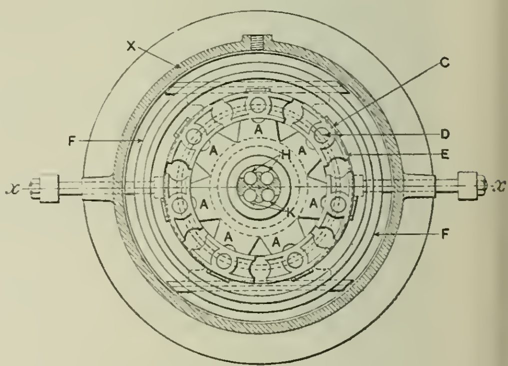


Fig. 22.

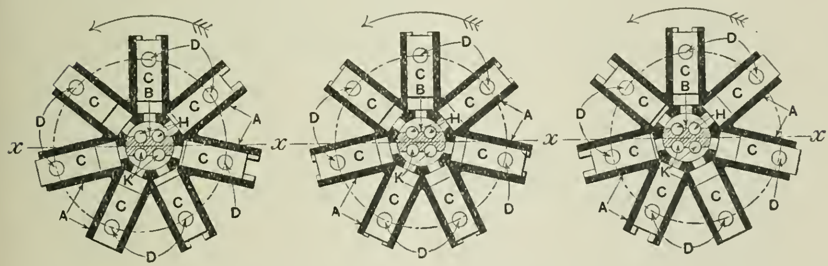


casing X by means of suitable passages. When the block of cylinders revolves, the floating ring F revolves with it, as the resistance of the slipper-pieces E is greater than that of the ball-bearings carrying it. In the central position the slipper-pieces have no movement, and in any other positions they only move to and fro to an extent directly proportional to the stroke of the pistons. If the cylinders are rotated in the direction of the arrows, and the path of the gudgeon-pins is concentric with the axle B, as in Fig. 23, no motion is imparted to the pistons, and therefore the pump is inoperative. If the path of the gudgeon-pins is moved to the left, as shown in Fig. 24, the pistons as they move above the centre line xx move outwardly, and therefore tend to create a vacuum, so that the oil is forced into the cylinders either by atmospheric pressure or by an artificial pressure in a supply-tank through the ports H^1 and H, while the pistons as they move below the centre line

xx move inwardly and discharge the oil from the cylinders through the ports K and K^1, the ports H^1 and K^1 being connected by suitable piping to the hydraulic motors. If the path of the gudgeon-pins is moved to the right, as shown in Fig. 25, the pistons move outwardly when moving below the centre line *xx*, and inwardly when moving above the line, so that the flow of the oil is reversed without altering the direction of rotation of the cylinders, the ports K^1 and K becoming the suction ports and the ports H and H^1 the delivery ports. In moving from the position of maximum delivery on one side to that on the other side, the discharge is gradually reduced until the central position is reached, when the delivery ceases, after which it again increases to the maximum with the flow in the opposite direction, the change from full forward to full reverse discharge being made without shock, the flow

Figs. 23 to 25.—*Diagrams of Hele-Shaw Pump. Compayne Hydraulic Gear.*

Fig. 24. Fig. 23. Fig. 25.



at all times being proportional to the eccentricity of the path of the gudgeon-pins.

The hydraulic motor, Figs. 26 and 27, is of a similar construction to the pump, but is of the constant-stroke type and works inversely. The novel feature of the motor is the employment of a cam as a track for rollers carried by the gudgeon-pins. Two motors are usually employed, arranged either one in each road wheel or both mounted on the chassis and each driving one of the road wheels by means of chain or other gearing. The gudgeon-pins D carried by the pistons C carry ball-bearing rollers M at their ends, which travel within a double cam N formed in or carried by the casing Y. Owing to the shape of the cam, the pistons make two strokes per revolution. This gives a complete balance of the working parts, an absolute and uniform turning movement, and obviates any shock in the system. By arranging the cam and the valve shaft so that they can both rotate at relatively different speeds, and making the cam of a corrugated or wavy form, a single revolution of the motor can be obtained from any desired number of strokes of the

Figs. 26 and 27.—*Hydraulic Motor. Compayne Hydraulic Gear.*

Fig. 26.

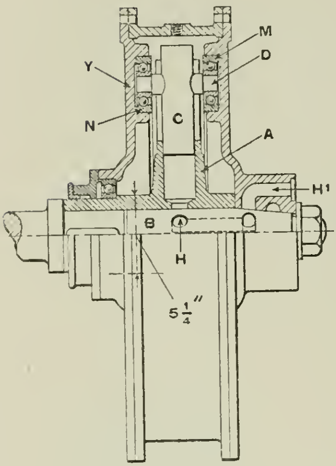
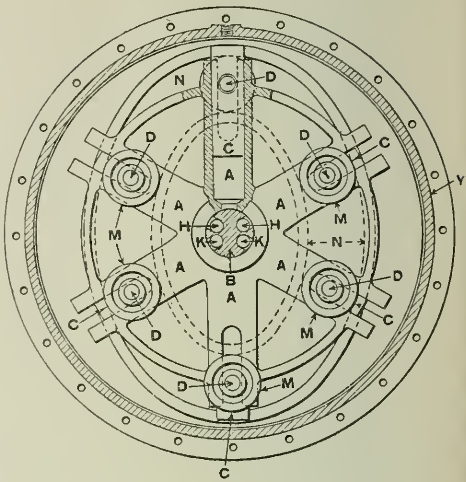


Fig. 27.



pistons of the pump. This enables a very great turning effort to be secured without unduly increasing the proportions of the motor.

Pieper Electric System.

In the Pieper, or Auto-Mixte, system, which is practically the same as the earlier British system of Farrow, a shunt-wound dynamo is mounted on a shaft which couples the engine with the road wheels through a magnetic clutch and suitable transmission gearing. The dynamo is connected through a controller with a battery of accumulators, and works either as a motor or a dynamo, according as its E.M.F. is inferior or superior to that of the battery. The dynamo is fitted with commutating poles, the windings of which are connected in series with the armature, thus ensuring good commutation with heavy currents and with a weak main field. The battery, although primarily employed for assisting in propulsion, can also be used for starting the engine and for ignition purposes. The supply of explosive mixture to the engine is controlled by the demand for current from the accumulators through a differentially wound solenoid, so that during starting and the period of extra effort the discharging current traversing its series-winding decreases the magnetism produced by the shunt-winding, which in turn increases the supply of mixture, and thus compels the engine to give its maximum power for a

given number of revolutions per minute. When the dynamo is charging the cells, the action of the series-winding assists that of the shunt-winding and tends to close the throttle. When the power of the engine is below that required, the battery automatically supplies energy to the dynamo, which then operates as a motor. When the power of the engine is in excess of that required for traction, or when the kinetic energy of the car can be recuperated, that is, when the car is slowing down or is running on a down-gradient, the dynamo works automatically as a generator and charges the battery. When the vehicle is on an up-gradient, and the torque on the road wheels becomes greater than the turning moment of the engine, the speed of the latter diminishes and the voltage of the dynamo falls until it becomes less than that of the battery. The battery then discharges into the dynamo, and thus produces torque, which assists that of the engine until it balances the resisting torque of the engine. On a down-gradient, if the resisting couple is less than the turning moment of the engine, the speed of the latter tends to increase, and the voltage of the battery rises so that the dynamo begins to charge the battery. As this charging current passes through the regulator the rate of admission of mixture to the engine is reduced to a minimum, and the torque of the engine becomes zero.

Stevens Electric System.

In the Stevens system a shunt-wound generator of the inter-polar type producing a continuous current is driven directly by the engine, and a series-wound electric motor is coupled to the transmission shaft of the vehicle, a controller box, and a shunt resistance for the generator fields being provided. The generator, which is capable of an output of from 1 to 36 kilowatts at a speed varying from 350 to 1,400 revolutions per minute at a voltage varying from 0 to 300, is designed with a falling characteristic, so that any increase in the demand for current when the engine is fully loaded is accompanied by a corresponding reduction in voltage. The output in kilowatts at any speed is proportional to the power exerted by the engine, but the volts and amperes vary over a large range, according to the gradient of the road, the speed, or the degree of acceleration required. The amperes required by the series-wound motor are approximately proportional to the torque on the transmission shaft, and the speed of the motor is to a smaller degree proportional to the voltage of the supply. Consequently, when the vehicle is running on a level road the demand for current is small, but on up-gradients it increases with a corresponding decrease in voltage, which results in a slower speed with increased torque. This change takes place automatically. The excitation of the generator ceases automatically when the engine speed falls below 250 revolutions per minute.

In ordinary running on the level, or on slight up-gradients, the speed of the vehicle is entirely regulated by controlling the speed of the engine by means of the usual gas throttle-valve; but on stiff up-gradients, heavy roads, under other conditions requiring greater power, the shunt resistance is employed to allow of increased engine speed. The controller has three positions—forward, neutral, and reverse. As the generator ceases to excite at 250 revolutions per minute of the engine, no electrical circuits are required to be made or broken in driving, even when stopping in traffic, as by reducing the speed of the engine to 250 revolutions per minute, or less, by means of the throttle-valve, the generation of current is stopped, and therefore no power is transmitted to the road wheels. Owing to the inter-polar construction of the generator, sparkless commutation is ensured, and as the main circuit is never broken during driving, no sparking occurs at the contacts. At starting, the electric motor demands a large current to develop the necessary torque for starting, which the dynamo supplies at a low voltage, and as the motor speeds up, it automatically demands less current, which is supplied by the generator at an increased voltage. In other words, the voltage of the generator varies in inverse ratio with the amperes output; therefore the power required to drive the motor can never exceed a predetermined maximum, which is arranged to correspond to the maximum power of the engine.

Germain Electric System.

In the Germain system, which of all the systems most nearly approaches the purely electrical change-speed gear, the electrical transmission is only employed while the vehicle is being accelerated to or driven at such a speed that the prime mover can deal with the load direct, at which time it is coupled directly to the transmission mechanism through a magnetic clutch. Two series-wound dynamos are employed. The field magnets of one dynamo are fixed on the crank-shaft of the engine and rotate with it and incidentally take the place of the fly-wheel, and the field magnets of the other dynamos are permanently fixed. The armatures of the two dynamos—each of which has its own commutator—are mounted on a shaft which is arranged in axial alignment with the crank-shaft of the engine and is connected to the road wheels by suitable transmission mechanism. The dynamo coupled to the engine acts either as a dynamo or as a magnetic clutch, and the other dynamo acts for the most part as a motor, but is also used as a dynamo for "braking" purposes.

Variations of speed of the car are effected entirely by a controller which makes the necessary electric connexions between the dynamo, the motor, and a variable resistance coil. Assuming that the engine has been started and that the car is at rest, the electric circuit is open throughout, so that no

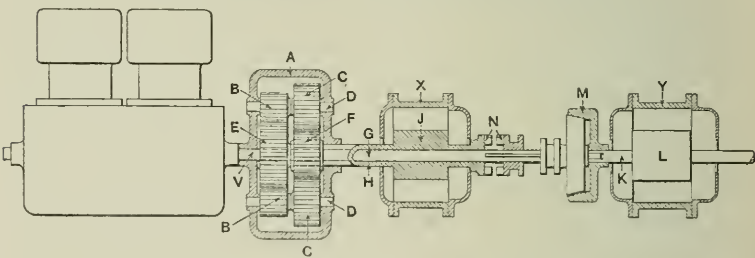
current is generated, and the armature of the dynamo remains stationary. To start the car, the controller is operated to connect the dynamo in series direct to the motor, whereupon the car will travel at a speed dependent on the work it is called upon to do. The power imparted to the driving wheels of the vehicle is now partly derived from the magnetic pull of the field magnets of the dynamo on its armature and partly from the pull of the motor. The faster the vehicle runs the more nearly the speed of the armature of the dynamo corresponds with the speed of the field magnets, and consequently the amount of current supplied by the dynamo to the motor becomes less and thereby reduces its speed and the amount of work it will perform. The reduction of current, however, also affects the pull of the field magnets of the dynamo on its armature, on account of the magnetism of both being reduced. On the other hand, the slower the vehicle runs the greater is the relative speed of the armature and field magnets of the dynamo, with the result that the clutch effect between these two parts is increased and the power of the motor becomes greater. To increase the speed of the vehicle, the controller is operated to introduce the resistance across the field magnets of the motor, which increases the speed of the motor and increases the current flowing through the main circuit, and therefore also the magnetic pull of the dynamo. By reducing the value of the resistance through the action of the controller, the speed of the vehicle can be gradually increased until the field magnets of the motor are completely short-circuited. When this result is attained there is only sufficient relative movement between the armature and field magnets of the dynamo to generate the necessary current to magnetize these parts, so that they operate as a clutch. To enable the mechanism to be used as a brake, the controller causes the circuit to be so altered that the functions of the dynamo and the motor are reversed.

Thomas Electric System.

In the Thomas system, which is diagrammatically shown in Fig. 28, the essential feature is the introduction of a planetary gearing, and it can best be described as an epicyclic gear in which the brake employed to retard or stop the rotation of one of the elements of the train takes the form of a resistance set up in an electrical machine, and in which the current generated in the electrical machine is employed to augment the power of the prime mover through a suitable motor. In this system three essential elements are employed, namely, a planetary gear and two series-wound electrical machines. The casing A of the planetary gear fixed on the crank-shaft V takes the place of the fly-wheel of the engine. The planet pinions B and C, of which there are two or more groups, are of different sizes, each group being mounted on a shaft D carried by the casing A. These planet pinions gear with

two sun-wheels E and F—also of different sizes—which are fixed respectively on a shaft G in axial alignment with the crank-shaft V and on the end of a hollow shaft H which fits over the extension G. On the shaft H is mounted the armature J of one of the electrical machines X, and on a shaft K, which is arranged in axial alignment with the shaft G, is mounted the armature L of the other electrical machine Y. The shaft K is coupled to the shaft G by means of a friction clutch M, and a couple in the form of a positive clutch N is provided between the shaft G and the shaft H. The two electrical machines X and Y are connected in series. There are thus two paths through which the power from the engine can be transmitted to the road wheels, the one a mechanical one through the pinion E and the shafts G and K, and the other an electrical path through the pinion F and the two electrical machines X and Y. Assuming a given rotation of the casing A, as the pinion E is larger than the pinion F, the pinion F and with it the shaft H and the

FIG. 28.—*Diagram of Thomas Electric System.*



armature J will tend to rotate backwards, and the pinion E and with it the shaft G and the armature L will tend to rotate forwards at speeds depending on their relative resistance to motion, and thus if the speed of the engine is constant, the speed of the shaft G will vary as the speed of the shaft H, and since the speed of H depends upon its resistance to motion and therefore on the load of the electrical machine Y, the speed of G can be varied by varying the power transmitted electrically between the armatures L and J, which is obtained by varying the strength of the fields of the two electrical machines by means of a suitable controller.

The operation of this transmission is as follows: Before starting there is no electrical connexion between the two electrical machines X and Y, so that the shaft H and the pinion F rotate backwards while the pinion E remains stationary. To start the vehicle, current is taken from the electrical machine X to the electrical machine Y. This has a double effect upon the shaft G. The current transmitted to the armature L exerts a torque on the shaft G, and the loading of the armature L with this current by decreasing

the speed of the pinion F and the shaft H causes the pinion E and the shaft G to rotate. A part of the torque is thus transmitted electrically and a part mechanically. As the armature J of the electrical machine X is gradually decreased in speed, the vehicle increases in speed until the shaft H, and with it the armature J of the electrical machine X, practically comes to rest. Up to this point the electrical machine X has been acting as a dynamo and the electrical machine Y as a motor. Both machines now change their functions, power being transmitted from Y to X. Owing to the shaft H being forced to rotate against and in the same direction as the engine, the speed of the shaft G still further increases. The speed of the shaft H increases more rapidly than that of the shaft G, due to the gear ratio in the planetary gear, until finally they both travel at the same speed. The coupling N is now engaged so that the engine drives direct through to the transmission shaft. To obtain the reverse, the coupling N is engaged and the clutch M disengaged. The armature J of the electrical machine X is then rotated by the engine and the current generated by the machine is transmitted to the electrical machine Y, which is given a reversed field. The electrical machine X—connected up as a shunt machine—may, when the engine is driving direct on to the transmission shaft, be employed to charge a set of accumulators, which can be used through the medium of the same electrical machine to start the engine.

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Discussion.

The Chairman (Mr. Michael Longridge, *Vice-President*) said it was unnecessary for him to propose the customary vote of thanks in view of the appreciative manner in which the Paper had been received. The Paper was of a kind with which the Institution was familiar in years gone by. It was a descriptive Paper; it did not propound any new theories or give the results of experiments of researches, but it described what had been done. With regard to such Papers, one thing he regretted that there was not space in the Journal for the introduction of larger drawings, with dimensions, the drawings being one of the most valuable features of Papers of this class. He was not himself the possessor of a motor-car, and had no knowledge of the difficulties incidental to the use of the various gear-boxes. The greatest compliment the members could pay to the Author would be to give the Meeting the benefit of their experiences of the gears described.

Dr. H. S. Hele-Shaw (Member of Council), in opening the discussion, said that the Author had succeeded in compressing into a small space the results of experiments which had, during the last twenty years, occupied the activities of innumerable engineers and inventors, and entailed an expenditure in various countries of millions of pounds. In stating the advantages and disadvantages of different systems, the Author had wisely avoided a comparison of their merits, but at the end of the Paper an invitation was extended to the upholders of particular systems to enter into discussion with each other. He believed, however, that additional information on the particular subjects with which speakers were acquainted would be more useful than a discussion of relative merits, and he therefore proposed to follow the excellent example of the Author, especially as the law of the survival of the fittest was probably more applicable to engineering than to any of the Arts.

Variable gearing might be divided broadly into two types, the "step-by-step" or toothed gearing, and the "continuous." He

(Dr. H. S. Hele-Shaw.)
preferred the phrase "continuous variation" to "infinite variation," because the latter was somewhat misleading, while the word "continuous" sufficiently indicated that the change proceeded by infinitely small steps. Up to the present the step-by-step system practically held the field, for he regarded the Author's estimate of 90 per cent. as under rather than over the mark; he thought a good deal more than 90 per cent. of motor-vehicles were fitted with gear-box change-wheels.

Many difficulties had been experienced prior to the present state of perfection of step-by-step gearing, and twenty years ago an engineer would have been positively appalled to contemplate the horse-power now transmitted by the small wheels of a modern gear-box. The research which had been involved in regard to the properties of steel to bring about this result, had been very valuable in other directions, and much had been discovered regarding nickel, chrome, and other steels now used. More difficult problems, however, were met in continuous variation, than even those of the change-speed gear-box, whether the system was hydraulic, petrol-electric, or of any other continuous variation type. The Author intimated (page 798) that the step-by-step system had held the field because of the increased flexibility of the petrol-motor, but he thought that many successful light cars owed much to the high power of the petrol-motor they carried. Thus the Ford car seldom needed to change gear at all, even in hilly country. Another excellent vehicle was exhibited at one of the Automobile Shows with the announcement of "no gear-box," but careful inspection showed that a small nest of change-wheels was employed for overcoming steepness of hills and possibly for starting. Owing to power and flexibility, one historic test under most varied conditions had been possible of a car having a locked gear-box, the engine being of the 6-cylinder type and the chassis fairly light. When, however, it came to a question of the heavy loads that would be carried in the future not only along roads, but where the roads were unsuitable for heavy loads on wheels, and for transport where there were no roads at all, quite enough was now known to be certain that loads of 10, 20, or even 30 tons, would be transported in the

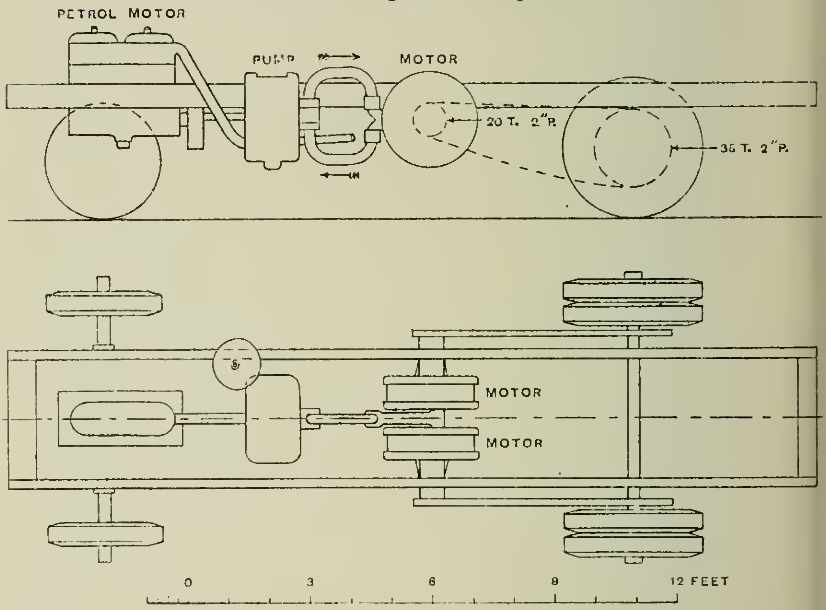
future, and it would be found that the continuous-variable gear would have its day and the hard and often unprofitable work done would reap its reward. He only used the word " unprofitable " in view of the present general use of step-by-step gearing for road traffic. Much money had been spent in developing, under difficult conditions, the continuous type of gear; but as, often before, in engineering history the results obtained for one object had turned out of even greater importance for others, and continuous-change gearing was being applied for a large number of purposes for which it was formerly impossible to use the high-speed dynamo or the petrol-motor. It pointed the moral of the old fable of the father who bequeathed the task to his sons of digging for an imaginary treasure, the reward for their trouble taking the form of an improvement in their land greater in value than the supposed treasure itself.

The Author had referred to two types of hydraulic transmission —the Hall and the Compayne—and these, it was interesting to note, differed from each other in principle almost exactly as did the Thomas and the Stevens petrol-electric systems. The principle of the Hall transmission was a beautiful one, and it would be seen by the carefully written description given in the Appendix (page 825) that, while there was a direct drive when the cylinders of the motor were working at their lowest capacity and the highest speed of the vehicle was obtained, the casing then rotating at the same speed as the driving shaft, as the gear came into operation a differential movement took place by the interaction of the pump and motor, and any required torque was obtained on the driving wheels. The reason why the Hall design had not come into general use was because of the difficulty which Mr. Hall, as a pioneer, had experienced in obtaining a suitable pump and motor, but the theory of his system was most ingenious.

Fig. 29 (page 840) showed the Compayne hydraulic system in its present form as applied to a 5-ton vehicle. This diagram merely located the pump and motor described by the Author, and it was evident that there was no direct or through top-drive. The Author had mentioned the efficiency of the hydraulic type of transmission,

and Fig. 30 gave a curve of efficiencies for one set. The overall efficiency was obtained by three careful series of tests, in which an electric motor was used to drive the pump and a dynamometer to measure the power taken from the hydraulic motor. The experience of numerous tests, many of which had been made under official

Fig. 29.—*Compayne Hydraulic System as applied to 5-ton Lorry. 40 to 60 H.P. Speed 12 miles per hour.*



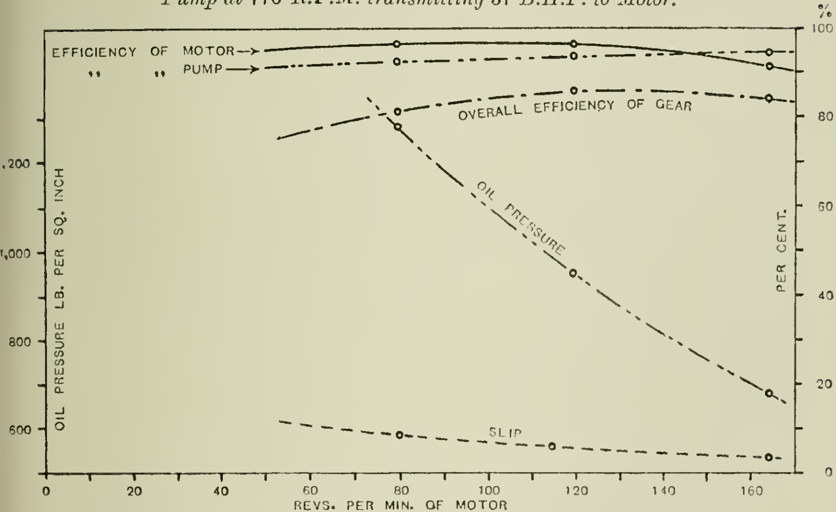
inspection, showed that the curves fairly represented hydraulic transmission efficiency.

The speaker had not been aware that the pump bearing his name was to be described in the Paper or he would have pointed out the vital importance of the floating ring referred to on page 828. This floating ring was the essential feature in the high efficiency of the pump, but its action was not very easy to understand, and he therefore exhibited a model to demonstrate the action of this contrivance. There was a point not alluded to in the description,

namely, the fact that the high speed of the pump was possible by the outward action in the suction stroke, thereby causing the effect of centrifugal force to reinforce the atmospheric pressure and prevent "separation" even at high speeds.

Coming now to the question of automatic gear-changing on which the Author has dealt at some length, it would be more correct to say the examples given by the Author should be really called semi-automatic gear-changing devices, and as far as the

Fig. 30.—*Efficiency of Compayne Hydraulic Transmission. Pump at* 770 *R.P.M. transmitting* 37 *B.H.P. to Motor.*



speaker knew there was no entirely automatic control of step-by-step gear-box. Take, for instance, the ingenious Linley device. In this case, as in others, the selection of the gear was made by moving a change-speed lever operating in connexion with the clutch as in other forms of control. A complete automatic variable gear would be one in which the motor-vehicle on arriving at a change of gradient would, without any intervention of the driver, have its gear varied automatically. Such results did not appear to be feasible except with continuous change-speed gears. Even with

(Dr. H. S. Hele-Shaw.)

any of the continuous change-speed gears mentioned by the Author, it was not a very easy thing in practice to obtain complete automatic control, although in theory the matter in any case was simple enough. As, for instance, the pump described on page 828, the hydraulic pressure tended always to put the pump in the no-stroke position, and a graduated spring-control could be made to give a discharge varying inversely as a pressure.

Quite recently the speaker had become acquainted with a new proposal for automatic control in transmission. The essential feature of the system was the employment of inertia in a different way to its employment in the fly-wheel. In the fly-wheel the energy of the rotating mass was stored up and given out as the speed of the motor fell with any resistance above the normal. In the new method, however, the motor actuated a revolving mass, and was not directly connected with the driven wheels of the vehicle. The revolving mass (which was capable of taking a variety of forms) was so supported that, as the resistance increased, the movement of rotation of the mass was exchanged for one of oscillation. This oscillation was most ingeniously arranged, so that neither in the acceleration or retardation of the mass was any energy lost except that in the friction of the working parts, and hence until the limit of torque was reached, and no motion of the following or driven shaft took place, the torque varied automatically according as the demand for it varied.

In conclusion, the speaker pointed out that the credit given the French at the beginning of the Paper was very opportune, as the perfection of variable gear had no small part in the effective transport which had played, and was playing, so great a part in the present war, and not only at Verdun, but at a very critical early stage, rapid road transport at the Battle of the Marne had almost certainly been the means of saving Paris and, with it, France itself.

Mr. EDWARD BATTEN stated that in 1915 when he was in New York he saw, while going along Broadway, a picturesque advertisement of the Owen Magnetic car, which described it as a

"car of a thousand speeds." While he could not claim that he had thoroughly examined the car, he thought there were some remarkable features about it which were likely to prove extremely valuable in the future. He would suggest, as one avenue of usefulness for such motor-cars, their utilization by those who had lost limbs at the Front, which would thus render them independent of their misfortune. The car in question had no gear-box or gear-levers; it had, however, a mechanical brake, which was scarcely ever used. There was no clutch. All familiar with motor-cars would know that the parts which wore out most quickly were the gear-box and the clutches.

The particular car he was referring to had a 30 h.p. engine, giving 50 h.p. at 1,500 revolutions per minute. It had a 6-cylinder engine, and he understood that the electrical equipment was such that it would absorb the full power of the engine running for an hour or two. The arrangement was, in the place of the fly-wheel, rotating field magnets, in the magnetic field of which was a generator armature fixed on the transmission shaft; on the same transmission shaft there was a motor armature, and stationary field magnets on the chassis. The car was self-starting, and carried an accumulator of about normal size. To start the car a switch was pulled out, which put the current from the accumulator into the motor. The engine then started in the ordinary way, and of course as long as the car was stationary there was a considerable current generated by the stationary generator armature, caused by the rotation of the field magnets. That current was led to the motor armature and the car started up. There was a controller similar to the quadrant and lever of an ordinary spark advance and retard, and at starting the whole of the power of the generator was transmitted to the motor. When the car was in motion, by merely moving the lever from one notch to another, the course of the current was changed and some of the coils were short-circuited, so that when running at what corresponded to top gear, the generator armature was short-circuited entirely; it was pulled round by the magnetic flux of the rotating field magnets. He was informed that there was about 5 per cent. slip, and he assumed

(Mr. Edward Batten.)

that that would be absolute loss; in that sense it must be less efficient than a car where the transmission was absolutely locked to the generator, but nevertheless it had many good points, with remarkable smoothness and flexibility. For instance, when the car was running along a hill, the driver had his foot on the accelerator; he took it off by degrees and the car gradually stopped. On the driver removing his foot entirely, the car ran down the track backwards; he again put his foot on the accelerator and the car started up the hill. In that way it executed a see-saw up and down the hill. It must be remembered that the driver was in New York, amongst the traffic; he did not manipulate the hand control at all, simply driving entirely on the accelerator, which, in view of the high power of the car, was nothing remarkable. The driver asked him whether he would be surprised if he could skid the wheels of the car, and he replied that he certainly would be, especially as he had been told that the action between the engine and the road wheels was absolutely elastic, that the wear on the tyres was exceedingly small, and that rushes, jerks, and bumpings were obviated. The driver then showed how he could skid the wheels.

He submitted the information to the Author for what it was worth, with particular reference to what the Author had said about speed of acceleration. It must be remembered that the car was of the ordinary touring type, with a 6-cylinder 30 h.p. engine. When the accelerator was pressed down by the driver both the back wheels skidded. A matter that had impressed him very much with regard to comfort in driving was that there was no need to pay any attention to graduating the braking; it was simply necessary to take one's foot off the accelerator and move the control to the braking position, and when the car drove the generator faster than the engine there was a reverse current in the motor, resulting in a magnetic brake between the revolving armature of the motor and the stationary field magnets. The mechanical brakes were therefore never really used save in emergencies—a very good thing at all events from the point of view of not wearing out brakes. He did not, of course, contend

that the car would run any better than, say, a Rolls-Royce; as a matter of fact, it was no smoother in running than the very high grades of British cars.

Mr. Thomas Clarkson said that the subject of variable-speed gears had a special fascination for mechanical engineers and had come into great prominence owing to the remarkable development of mechanical road-vehicles. The variable-speed gear was really vital to the success of road transport. A great deal of time and energy had been lost owing to slavish adhesion to the old tradition of the steam locomotive, which, of course, had no variable gear. The steam locomotive was very flexible, and the engine was always directly coupled to the driving wheels; there was no change-gear. It must be remembered, however, that the conditions were essentially different from those found on an ordinary road. In the first place, on a railway there was always a hard surface, whereas on a roadway the surface was sometimes very soft. In addition to that, the grades on the road were much steeper than those on a railway. He frankly confessed that he had taken a pride in stating that a steam-omnibus could be run without a gear-box—as a matter of fact, they were run in that way successfully—but it had to be admitted that no engine could do itself justice, could overcome considerable obstacles and develop its full power, without a chance of getting a reasonable piston-speed. If, therefore, the principle of the change-gear box were accepted—even for the steam-engine, the most flexible type—there was the advantage of a much lighter and simpler engine, and the advantage also of a free engine. That was a very important condition when it was remembered that a commercial car had frequently to wait for fairly long periods, when, under ordinary conditions, the engine became cool and more or less water-logged.

The success of the gear-box was, of course, entirely bound up with the efficiency of the friction clutch. In order to take full advantage of the gear-box there must be a very efficient form of friction clutch, a subject with which Dr. Hele-Shaw had not dealt to any extent in his interesting dissertation, although he believed

(Mr. Thomas Clarkson.)
Dr. Hele-Shaw was responsible for the introduction of one form of friction clutch. The clutch had been brought to a very high degree of efficiency, and he thought that it would be accepted to-day as a very matured type of mechanism. So far as he was aware, the most satisfactory and efficient form of clutch was the single plate clutch, having a hardened-steel plate between asbestos frictional material. By the employment of such a clutch, in combination with the gear-box, the most efficient speeds to enable the engine to develop its full power could be obtained.

With regard to the development of the gear-box, the early types seen in France were very crude, and it seemed a very wrong method of treating machinery to bring tooth-gears into mesh by sliding them along the axis. But, notwithstanding that, it was wonderfully effective and efficient, and the question of engaging—which was, of course, where most of the wear occurred—rendered it necessary to have a very hard material, capable of withstanding rough treatment. The wear developed noise, and for London omnibuses, in order to comply with the Scotland Yard standard of quietness, it was necessary to have a chain instead of a spur drive. With the greatest possible care in the shaping of the teeth of the spur, they could be made to run fairly quietly for a time, but after wear they became noisy, and in that respect the inverted link type of chain drive had a very marked advantage, being the only type of gear-box which had proved successful for omnibus work in respect to quietness. He believed that the petrol-electric transmission was really devised to overcome the difficulty of the noise of the ordinary spur-gear box, but he was of opinion that the chain-gear box had rendered the petrol-electric system, with its extra complication, unnecessary for the attainment of variable speeds on omnibuses.

Mr. A. E. Parnacott considered the efficiency of the transmission had been overlooked. As he considered it, the prime object of interposing a variable gear was to give a variation of the quantity of fuel consumed per ton per mile. Sixty to sixty-five litres of mixture would give one horse-power; the power available therefore

depended upon how many litres could be consumed in a given time, and it was the function of the change-speed gear, on the lower gears, to enable the engine to run faster relative to the car-speed and thus consume more combustible mixture and to have more power available per mile travelled. It was therefore important to have an efficient transmission, for the prime mover had to be carried.

He noticed that the title of the Paper was not the "Gear-Box" but "Variable-Speed Gears," which permitted him taking a complete view of the transmission; the transmission was of extreme importance, especially in war time, when vehicles had to travel over extremely bad surfaces; the distribution of weight was important, particularly so in propulsion up steep gradients, for sufficient weight must be impressed on the driving wheels. With the orthodox car arrangement of chassis it was impossible to negotiate the heaviest gradients and surfaces both loaded and unloaded, as the weight on the driving wheels was insufficient unloaded. The remedy appeared to be the four-wheel drive, but this necessitated three differential gears, one to each axle and one between them, when any one wheel might spin round on a greasy surface without propelling the vehicle. A remedy might be the hydraulic gear, but he considered it as having fundamental disadvantages, namely, for tolerable efficiencies the speed of the motor, pump, etc., was so low that it was necessary to have some speed-gear interposed between the engine and the pump, and again between the hydraulic motor and the transmission to the road wheels.

Dr. Hele-Shaw being an eminent engineer, he must assume no mistake had been made in the dimensions of the chassis, Fig. 29 (page 840); it would seem that the oil-pump and motors each weighed as much or more than the prime mover itself. The weight apparently was excessive, one pair of wheels alone being driven. For transmitting energy from the motor to the four wheels there was, apparently, only one alternative, that is, the petrol-electric system for heavy freight transit, particularly for the Army. It had proved a success on the London omnibuses, and he could see no reason why it should not be developed to displace the sliding-

(Mr. A. E. Parnacott.)
gear transmissions. With this petrol-electric system the changes of speed were gradual rather than in steps, and it lent itself admirably to four-wheel drive and the locking of the differential effect electromagnetically.

He had already referred to the volume of charge burned per ton-mile, and this he considered the crucial question relative to variable-speed gearing. The Ford car had a capacity for consuming a very large amount of petrol vapour, and consequent of driving so much with a partly-closed throttle the fuel consumption, instead of being for a 14-cwt. vehicle something like 35 to 40 mile per gallon, was 25 to 30 miles. It was possible to design a vehicle which would have no change-speed gear, provided the engine was of sufficient size to climb the steepest gradient, but unless the cycle of engine operations was varied, the effect of varying the volume of mixture per ton per mile by the throttle would be a heavy fuel consumption in miles per gallon.

Mr. HEDLEY J. THOMSON remarked that the Author had made reference to the Thomas transmission, and had he been earlier aware of the Paper he might have been able to give more interesting and recent information that was obtainable from the comparatively unknown reports of the Royal Automobile Club. Mr. Thomas, who was prevented by illness from attending the Meeting, hoped to send in a written communication. Meanwhile the speaker would like to refer to the Owen Magnetic car which Mr. Batten had mentioned. That car belonged to a type which had been described in the Paper as the Germain type. It had not, however, been pointed out in the Paper that in this type a large torque was always transmitted mechanically. In the case of the Owen car, this mechanical torque was the magnetic drag (always equal to the engine torque) between the rotating field magnet and the armature. It followed that the remark made in the Paper, that the electrical machines had to be sufficiently large to deal with the whole power, was not quite correct; that system, and the system known as the "Thomas," had in common the characteristic of dealing mechanically with a large proportion of the power. The

"Thomas" dealt mechanically with a greater amount of power than the "Owen," and had a direct mechanical drive on top. The speaker did not think it was necessary to go to America to obtain all the valuable features outlined by Mr. Batten in relation to the Owen machine.

Mr. Clarkson had contended that the chain gear-box had practically rendered unnecessary the petrol-electric and hydraulic systems of transmission. The speaker considered, however, that silence was not the only consideration, and that as the question of efficiency should be borne in mind, it was necessary to secure a wide and flexible range of torque without loss of power, a result impossible with a gear-box, having only three or at most four speeds.

Reference had been made in the discussion to the possibility of getting a drive on all four wheels, and it had been pointed out that the mechanical systems, and also the hydraulic, suffered from certain disadvantages in that respect. Many would perhaps have seen the road train which had been running in London for some time, in which electric power was transmitted to the trailing vehicles—to all rear wheels of a train of three vehicles. It was certainly the case that for such applications the petrol-electric system had an advantage not possessed by the other systems. (*See* also page 858.)

Mr. O. R. Opperman said the Author mentioned that the success of the ordinary sliding type of gear was due to the great attention it had had, and also because most of the running was done on direct drive. He thought he was right in saying that the perfection during the past few years of direct hardening alloy steels, such as "Martino's," "Kayser, Ellisons," "B. N. D.," and other well-known makes, was answerable to a great extent for the reliability of this type of gear.

With regard to the causes of noise in gear-boxes, he would like to offer further suggestions, based on practical experience, to those already given by the Author, as the reduction of noise was an all-important factor. Admitting that the peripheral speed must be

(Mr. O. R. Opperman.)
kept low, it was advisable not to keep it so low that it was necessary for the first speed driving pinion to be as small as 12 T. A pinion with so few teeth was, as a rule, noisy. This was not of so much consequence with a pleasure car, as the first speed was seldom used, but it was very necessary with commercial vehicles. Pinions of 12–14 teeth should always be avoided where practicable, as the driving motion from one tooth to the next was through such a wide angle, being 30° with 12 T.

While referring to noise, it would no doubt be of general interest to record an experiment made some years ago, comparing the noise between standard depth teeth and stub teeth. It was the outcome of a hub gear which he brought out, the teeth of which broke every now and again. The stub tooth wheels did away with the breaking, but unfortunately the noise was excessive. Teeth with various pressure angles were also tried, but with the same result. He then resolved to make a test in the works with two pairs of gears with 7 D.P. and 7/8 D.P. stub teeth; and they were left in their natural state in order to keep them as accurate as possible. They were carefully mounted on stiff shafts. The result was that the stub wheels made considerably more noise than the standard gears.

An important point to be noted by automobile engineers was the fact that with stub teeth the rolling surface was very much smaller, whereby the co-efficient of friction was increased, and the efficiency of the gears reduced. It was also only to be supposed that stub teeth wore away quicker than standard teeth. Much noise was caused by the result of inattention to seemingly small details, such as the change-lever joints and connexions, which were left unhardened; these, after a short space of time, wore unduly, causing "sloppiness" or back-lash, allowing the gears to get out of line and wear away on one side only. To obviate this, all working parts should be hardened and forks should be made as stiff as possible, have oil ways, and be hardened and ground.

He agreed with the Author in using double helical wheels wherever possible, and when designing them, the angle of spiral should be such that before the tooth on one side of the wheel left

the space, the next tooth was already well engaged. In other words, the minimum spiral angle should be Tan $\theta \frac{\text{circular pitch}}{\text{width of face}}$. With single helicals there was too much side-thrust when the angle was sufficient to eliminate noise. One often saw timing wheels with helical cut teeth of an angle of 10° or less, which of course were useless for the purpose for which they were intended. He thought there was a long future for the sliding type of gear, but, at the same time, the sooner one with a wider sphere of changes was devised the better.

Mr. Robert E. Phillips, in reply, said that in order to keep the Paper within reasonable limits, he had had to avoid going into matters of constructional detail. No one was better aware than the speaker how the Paper had suffered from the restriction necessitated by space considerations, a fact which would answer any criticism of omissions.

He agreed with Dr. Hele-Shaw as to the "survival of the fittest" in engineering matters, but he scarcely thought it would apply in the case of variable-speed gearing, otherwise the sliding type of gear must be accepted as perfection. He accepted Dr. Hele-Shaw's correction as to the term "automatic change-gear"; that, however, was the name generally borne by the type, but, of course, it was really only semi-automatic, inasmuch as some mechanical movement had to be made by hand. Many years ago a purely automatic change-gear of the step-by-step type was exhibited at the annual Automobile Show in Paris, but it was never taken up commercially. In this gear a governor on the engine operated to change the gear up or down as the speed of the engine increased or decreased above its critical speed.

Referring to Mr. Batten's description of the "Owen Magnetic" car, the petrol-electric system employed in this vehicle belonged to the second type, as classified in the Paper, of which the Germain was given as an example. So far as he was aware, the "Owen Magnetic" had never been introduced into this country, but the "Germain system" was exhibited here at least twelve years ago. It was unaccountable that this system had not been a

(Mr. Robert E. Phillips.)
greater commercial success, to which its potentialities seemed to point.

Mr. Batten had referred to the tests he had seen to prove the rapid acceleration of the Owen Magnetic car, but he would like to suggest that most probably what Mr. Batten regarded as rapid acceleration—which produced the skidding of the wheels referred to—was due either to the greasy condition of the surface of the road or to there being insufficient weight on the driving wheels to maintain adhesive contact.

He agreed with the opinion of Mr. Opperman that the success of the sliding-gear was due in part to the present methods of hardening and treating steel, but he thought that point was covered by his statement to the effect that the success of the sliding type of gearing depended upon a very high standard of workmanship and the use of high-grade materials. He regarded the experiments made by Mr. Opperman with stub teeth as very interesting. He thanked the members for their cordial reception of the Paper.

Communications.

Mr. E. A. Barnwell wrote that the Author stated (page 803) that one of the advantages claimed for the third system as compared with the first and second petrol-electric systems mentioned, was that on the higher speeds the drive was practically "mechanical," with electrical losses reduced to a minimum. This advantage, the writer gathered, referred to economy or efficiency. Actually it was on the higher speeds that the economy or efficiency of the second system was most marked. As far as the Tilling-Stevens design was concerned, it was admitted that the efficiency, as regards petrol consumption at slow speeds, was low, yet the petrol consumption of a Tilling-Stevens vehicle (which was designed to operate exactly as described in the second system) compared favourably with any mechanically-propelled vehicle. It was therefore obvious that a

high efficiency must be obtained at the higher speeds of the vehicle compared to a purely mechanical drive. This increased efficiency was unquestionably due to the fact that the speed of the engine was in no way governed by the speed of the vehicle, as was bound to be the case in a mechanical drive.

With regard to the question of braking electrically, the Tilling-Stevens Co. had never considered it worth while to introduce this. It was interesting to note, however, that the motor of a Tilling-Stevens vehicle acted as a safety brake when stopping on hills, because, should the vehicle commence to run backwards, the motor would immediately generate back on the dynamo, and effectively brake the vehicle. This was very often a forgotten advantage of the petrol-electric transmission over a gear-box, because, should a driver miss his gears when changing on a hill, there was always a danger of the vehicle running back.

Another advantage of a petrol-electric vehicle when on a hill was the ease of starting without any fear of running back, because the brake could be kept on until the engine was speeded up and maximum torque was being exerted by the motor, when the brake could be eased off, and the vehicle would immediately move forward without shock or jar of any kind.

With regard to the fourth system, the Author stated that it was considered more economical than a direct electrical transmission. A test made with a Tilling-Stevens lorry which had been in service for about eighteen months, and without making any adjustments, gave the following results:—

Gross weight	8 tons 3 cwt.
Tare weight	4 ,, 1 ,,
Useful load	4 tons 2 cwt.

Petrol consumption, 7·75 miles per gallon.

This worked out at 63·16 ton-miles per gallon, calculated on the gross weight, compared with 58·046 ton-miles with the Thomas transmission, while the useful ton-miles per gallon worked out on the Tilling-Stevens to 31·5 as compared to 24·03 on the Thomas transmission, showing an increase of over 31 per cent. compared

(Mr. E. A. Barnwell.)
with the Thomas. The above figures only affected actual fuel economy, whereas on the Tilling-Stevens, owing to the low speed of the engine compared to the speed of the propeller-shaft when the vehicle was travelling at top speeds, considerable economy was obtained in the wear and tear of the engine and other parts.

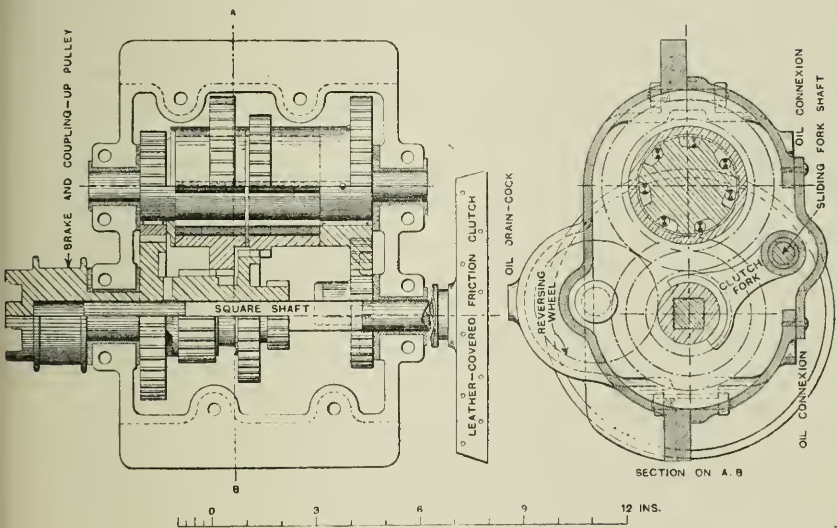
The Author's remarks with regard to acceleration of petrol-electric systems came as a considerable surprise. As far as the Tilling-Stevens transmission was concerned, the acceleration had always been considered to be superior to a mechanical transmission. With regard to a means of obtaining accurate data concerning the transmission losses under road conditions, it was a comparatively easy matter to do this on a Tilling-Stevens vehicle by obtaining engine speed, dynamo output, and speed of vehicle. From these figures it was possible to, and Messrs. Tilling-Stevens actually did, reproduce road conditions on the test-bed.

Mr. Alfred Crossley wrote that the Author mentioned on page 789 a gear in which the driving couple was by means of a one-way clutch, which was abandoned on account of the complications involved in this system. From his description the Hitchon gear, Fig. 31, was apparently indicated. This gear was tried on several cars in the North Lancashire district with very good results. From an historical point of view it was worthy of inclusion in such a Paper as this. It was a decided advance upon gears in use at that time. It would be seen that it was of the straight-through type, the elements upon the secondary shaft having hubs of large diameter, inside which were arranged rollers and inclined planes, the whole being a collection of free wheels so arranged that the various elements were in mesh on top speed, each higher speed wheel-hub rotating in advance of the following one, so that the various speeds were picked up automatically when the sliding pinion was withdrawn out of gear with the individual elements.

From this it would be seen that in coming down from a higher to a lower speed the change was accomplished with an utter absence of noise or jar. The top speed wheel was coupled to the sliding pinion by means of a dog-clutch; second and third speeds—and in a

modification a fourth speed—were arranged upon free hubs ; reverse was accomplished in the usual manner by means of an idle wheel mounted upon a stud. One of the principal objections to its use advanced at that period was that in going down hill the engine could not be used as a brake. This gear was installed in an Argyll car in 1901, and when tested for wear after over 5,000 miles running, none could be detected with the micrometer. Another one was tried

Fig. 31.—*Hitchon Transmission Gear for Cars* 10 *to* 20 *H.P.*, 1902. *Aluminium Gear-Box. Gears* 8 *D-Pitch.* $\frac{7}{8}$*-inch faces. Rollers* $\frac{5}{16}$*-inch diam.*



in a car weighing 31 cwt. and subjected to very heavy duty over several thousand miles, running with equally successful results. This was arranged with four speeds and reverse, and was embodied in the Globe car of that date. The writer heard the other day of one of these gear-boxes which had never had any replacements since coming into its present owner's possession four or five years ago, although the car was in constant use for all kinds of purposes.

Mr. Charles E. Holliday wrote that, under the heading "Silence in Gear-Box" (page 791), the Author gave eight essentials

(Mr. Charles E. Holliday.)

for silent running when using spur-gear, but in speaking of the advantages of chain-gear he did not go so fully into the reasons why chain-gear overcame so many of the objections mentioned with regard to spur-gear, and the three advantages mentioned hardly gave the best case for the chain-gear.

Referring to advantage (1), there was certainly resilience about the chain-drive, but hardly sufficient to act as a "safety-valve" for careless driving. In fact, the chains in use at present had not such a high factor of safety but what they sometimes broke if the driving were very bad. In advantage (2) it might also have been mentioned that the reverse was obtained with the additional advantage of avoiding an extra shaft for it. With regard to advantage (3), it might be thought that although the chains could be renewed so easily, the wheels would involve the same trouble as renewing spur-wheels. It would perhaps be as well, therefore, to explain that in gear-box work it was found that scarcely any wear took place on the chain-wheels, and one set of wheels would outlast three or four chains.

The difficulties with regard to spur-gear might be summarized by saying that, for quiet running, a very high degree of accuracy and finish was necessary, and the advantage obtained therefrom was of short duration owing to various causes mentioned—such as slight wear in the bearings, spring in the shafts, and distortion of the casing—which threw the wheels out of their true setting.

It would probably be of interest to many to set out the features of the chain-gear and the reasons why it gave quiet running. The features of the gear as considered in relation to this application were that:—

(*a*) Whilst chain-gear must be well and accurately made, the limits were such that it could be produced under manufacturing conditions giving interchangeability, and neither faking nor pairing nor running-in was necessary.

(*b*) Compared with spur-gear there was a wide range of tolerance as regards the running conditions, and such

wheel displacements as were due to the causes given by the Author did not seriously affect the smooth and quiet running of the gear.

(c) More choice was given in the selection of ratios, and it was easier to provide exceptional ratios for special conditions.

The main reasons for quiet running were:—

(1) The load was distributed over a number of teeth.

(2) Chain engagement with wheel took place with scarcely any sliding action.

(3) Due to its wedge shape the chain filled the wheel-teeth and allowed of no back-lash or rattle.

(4) There was a certain amount of elasticity in the chain, partly due to slight spring, but chiefly to the number of oil spaces in the joints, and this had the effect of softening the drive.

(5) Within wide limits, noise did not develop with wear, as the wear occurred chiefly in the joints and not on the gear faces.

As to the history and development of the chain gear-box, the writer suggested that the Author might add to his list of references the article on the "First Chain Gear-Box" in *The Commercial Motor* of 12th March, 1914. In this article the introduction of the chain-box on the London omnibuses was dealt with in a very clear manner. It also gave a drawing of the chain gear-box as fitted in a Leyland vehicle in 1898; this was arranged with Hans Renold silent chain. Another drawing showed the Brooke gear-box, arranged with Renold roller-chains, first built in 1901, and it quoted a letter from Mr. Brooke, written in 1914, saying how satisfactory these boxes proved in practice.

It might be mentioned that later experience showed that there was considerable scope for the use of roller chain in gear-box work. It had many of the advantages of the "silent chain," and, although it might not be quite as quiet, it had the advantages of being about half the weight and half the width of a "silent chain" of similar strength and bearing surface.

(Mr. Charles E. Holliday.)

As regards the London omnibuses it might be said, without detracting from the credit due to the Coventry Chain Co., that theirs was not the only chain that had been in use from the earliest days. The Renold silent chain with a special liner bearing was fitted to the Straker omnibuses in 1910, and had been continuously supplied in large quantities since both for London omnibus work and for various other vehicles in service on London work and for more hilly districts outside.

The firm of Hans Renold, Ltd., had also a "silent chain" with liner bearing which was suitable for running on the existing standard wheels of London omnibuses, and which gave, as compared with the present standard chain used on the "B" type omnibuses, a larger bearing area and an increased breaking strength of about 50 per cent. A number of these chains had recently been under trial on London omnibuses. Another type of Renold silent chain had been tried in an English-made 15 h.p. touring car, and on the last examination the whole gear was found to be in excellent condition after the vehicle had done 22,000 miles.

With regard to chains for other purposes than for omnibuses, there seemed to be a misapprehension amongst designers with regard to the chain-speed. The chain-speeds in the gear-box of a touring car would of course be higher than omnibus practice (where the speeds were quite moderate), but they were not excessively high. This misapprehension was probably caused by the Maudslay gear-box, the arrangement of which gave much higher chain-speeds than would be necessary with a design such as would be used at the present time.

Mr. Hedley J. Thomson wrote, that on page 784 it was stated that, with the adoption of the high-speed petrol-motor, the importance of variable-speed gears became prominent, "by reason of the fact that the speed of maximum torque of a petrol-engine is practically at full power, and as the speed decreases so also does the torque." The words quoted hardly expressed the true reason or the actual relationship of power and torque. It was well known that the maximum torque of the internal-combustion engine

differed only slightly from its torque at the lowest speed at which it would run on full throttle, and that it would produce no torque when at rest. In this respect it differed essentially from the steam-engine, which, as its speed decreased, could be relied upon for a considerable increase of torque. Further, it was well known that, to obtain the most efficient results, an explosion engine must be run at constant, or nearly constant, speed, with conditions carefully and correctly adjusted as to fuel mixture, compression, and ignition. These, it was submitted, were the true reasons why the importance of variable-speed gears came into prominence with the introduction of the high-speed petrol-motor.

It was stated (page 796) that some makers employed a double reduction at the back axle, and it was suggested that the object of this arrangement was to keep the wheels of each pair in the gear-box, giving the various speeds of a more uniform size. Such a double reduction was now almost exclusively confined to heavy commercial vehicles, and its object was to get a large reduction more conveniently than would be possible with a simple bevel, and not the question of uniformity in the size of gears in the gear-box proper, this being determined solely by the torque range, for which the gear-box was designed.

With reference to the Pieper or Auto-Mixte system, it was not correct, as stated on page 802, "that the engine and dynamo run at a constant speed, which enables the former to be run to the best advantage and enables the latter to produce a current of suitable voltage to charge the accumulators at the proper rate"; in this system neither the petrol-motor nor the generator could run at the most suitable speed, as they were so coupled that in service each ran at a speed proportional to the vehicle speed. This inflexibility was in fact one of the disadvantages of the system.*

With reference to the Stevens transmission, it was stated on page 802 that "the over-all commercial efficiency running in normal omnibus service is 79 per cent." It was not made clear what this "over-all commercial efficiency" was. If this term

* Proceedings, I.E.E., May 1913.

(Mr. Hedley J. Thomson.)

related to the transmission mechanism, then the petrol consumption and general upkeep were irrelevant from this point of view. If, on the other hand, it was some vague comparative efficiency, further information should be provided if the percentage was to be of value as a guide to other engineers. In a Paper dealing with variable-speed gears, engineers not well acquainted with the subject might be excused for accepting this figure as a transmission efficiency pure and simple, and in so doing they would be much in error, as a pure electric system such as the Stevens transmission would seldom afford so high a transmission efficiency under normal running conditions.

In reference to the Germain system of transmission (page 803), it was stated that "the double commutator adds to the complication of the control." This statement was rather misleading, in that in this system there was not a double commutator in the sense that these words were usually employed. So far as commutators were concerned, this system involved the use of a generator with one commutator and a motor also with one commutator, and in this respect it was no more complicated than any system involving the use of both generator and motor such as the Stevens. The main disadvantage of the Germain system, and one which has only recently been partially or wholly overcome by Owen in America, had been the complication involved in the employment of brushes which must revolve with the field magnets. Despite Owen's refinements, it would appear that this system would be limited to equipments of comparatively small output.

The Author suggested (page 804) that petrol-electric vehicles were at a disadvantage on account of excessive weight and lack of power of rapid acceleration. It was true that for pleasure and light commercial vehicles the question of extra weight could not be ignored, but if the system were one in which a large proportion of the power was transmitted mechanically, and if, in addition, the system rendered unnecessary the addition of a separate electric lighting and starting equipment, the extra weight was not a bar, even for comparatively light vehicles, and it made very little percentage difference in weight on heavy vehicles.

As regards the question of acceleration, he (the writer) would join issue at once with the Author, as there was no doubt whatever that with a properly designed petrol-electric system, such a wide torque range could be obtained, and the transition from one speed ratio to another could be so easily made without temporary cessation of the driving power by de-clutching, that much higher average acceleration could be obtained than was possible with a gear-box and clutch, it being assumed that in each instance the engine-power was the same. With properly designed series machines, after making a change in the control, the effect was almost instantaneously felt at the driving-wheels, there being no appreciable lag, as stated.

In summing up his remarks as to the change-gear box, the Author stated that one of the possible further improvements would be "the all-round use of wheels having helical teeth." This, of course, pre-supposed the general adoption of gear-boxes of the type having gears always in mesh, and although such a change might be made, it was unlikely to become universal, particularly as practically all the advantages of helical teeth and others in addition could be obtained by the use of straight ground gears, such as were now being made by the Gear Grinding Co. of Handsworth, Birmingham, for the Daimler Co., Dennis Bros., and other leading firms.

This gear grinding process was an extremely interesting one from a mechanical engineer's point of view. The gear-blanks were first rough cut, leaving from 0·01 to 0·02 in. of stock all over the flanks of the teeth to allow for possible distortion during hardening. Then the gear was either case-hardened or hardened as a whole in any manner suitable to the particular steel used, and after the bore had been ground out accurately the piece was mounted on a mandrel and placed in a special grinding machine, by which the gaps between the teeth were ground out by a wheel having the exact profile required. Wear of the wheel was counteracted by regular dressing by a diamond, the position and motion of which were mechanically controlled by a mathematically correct former or master-gauge. Gears made by this process could be glass-hard and absolutely smooth and correct in shape, so that they would run indefinitely without appreciable falling off in efficiency.

Mr. Robert E. Phillips wrote that the figures given by Mr. Barnwell (page 853) respecting a test made with a Tilling-Stevens lorry certainly showed that the Stevens transmission was more economical than the Thomas transmission, but as no statement was made as to the conditions under which the test was made the comparison could only be accepted as *ex parte*. The Author held no brief for the Royal Automobile Club, but, as this Club has been universally accepted as the authority for carrying out automobile trials in this country, he ventured to suggest that the merits of the Tilling-Stevens transmission would be considerably enhanced and its suggested economy as compared with the Thomas system would be more acceptable, if a vehicle fitted with it underwent a trial under the auspices of this recognized body.

As regards acceleration of petrol-electric systems, it must be borne in mind that the point raised in the Paper was the power of rapid acceleration and not merely the question of the effect of acceleration on the vehicle. It could safely be conceded that the acceleration produced by a petrol-electric system was superior, from a point of view of transmission stresses and shocks, to that of a mechanical system, and so far the Author was in accord with Mr. Barnwell. With regard, however, to rapidity of acceleration, no tests, so far as the Author was aware, had ever been made to prove that this power was greater with a petrol-electric system than with a mechanical system. Failing such a test, for which means and opportunity existed, one could hardly accept any statement that one system was *considered* superior to others except at its face value. It was interesting to know that it was a comparatively easy matter to obtain accurate data concerning transmission losses under road conditions on a Tilling-Stevens vehicle, and the publication of such data would be a welcome addition to existing knowledge. It was, however, as well to recognize that actual road conditions cannot be reproduced on a test bench.

Mr. Crossley (page 854) was right in assuming that the gear referred to on page 789 was the "Hitchon." The very satisfactory service which this gear had apparently given in actual practice seemed to emphasize the reason furnished for its abandonment.

Mr. Holliday's amplification of the advantages of the chain gear-box (page 856) were most pertinent, and only the exigencies of space prevented the Author from going into these more in detail. There was, however, one point on which the Author joined issue with Mr. Holliday, namely, that the use of chain-gear gave more choice of the selection of ratios. One of the chief difficulties which arose in the use of this type of gearing was—as stated in the Paper—the finding of suitable wheels to run at a common centre distance to produce the desired speed ratios.

With respect to Mr. Thomson's remark (page 859) on the "over-all commercial efficiency of the Stevens transmission," it should be apparent from the context that this "over-all efficiency" was not intended to cover purely transmission efficiency. The Author had dealt with the question of rapid acceleration in commenting on Mr. Barnwell's communication, and he could only reiterate the hope that a trial under a recognized authority would be made to test the power of rapid acceleration of vehicles fitted with petrol-electric systems so that this question could be conclusively settled.

In suggesting the all-round use of wheels having helical teeth, the Author did not pre-suppose the adoption of gear-boxes in which the gear-wheels were always in mesh. On the contrary, he had in his mind gear-boxes in which the wheels were brought into engagement by the usual end-on sliding movement. Considerable progress had already been made along this line, and the problem seemed to resolve itself entirely into the best means of balancing the end-thrusts, without effecting the easy engagement of the wheels.

FIRE PREVENTION AND EXTINCTION: *

WITH SPECIAL REFERENCE TO THE CONDITIONS APPERTAINING IN INDIA.

By BERNARD A. WESTBROOK, Chief Officer,
Calcutta Fire Brigade.

[*Selected and Abridged for Publication.*]

This Paper deals with methods adopted in modern practice for the prevention and extinction of fire. The fire loss per annum in the British Isles alone has been estimated to be about 2*s.* 3*d.* *per capita.* In the United States the annual loss by fire *per capita* is about 10*s.* 11*d.*, and in Canada slightly more, these high figures being attributable to the large amount of timber used in, and the inferior construction of, buildings. This waste, which amounts to nearly 50 million pounds per annum, is now receiving the attention of the Legislative Departments.

Germany passed laws regulating the erection of buildings, storage of inflammable materials, installation of fire preventive devices, and moreover recognized the principle of "individual responsibility," and thereby reduced the annual loss *per capita* to 10*d.*, a remarkably low figure when the huge manufactories and industrial centres are considered.

* This Paper was read and discussed at a Meeting of the Calcutta and District Section on 24th November 1915. A copy of the complete Paper may be borrowed from the Institution Library.

In France, where the fire loss *per capita* is not so low as in Germany, "individual responsibility" is also recognized. If a fire starts in any premises through carelessness or culpable fault, all damage to neighbouring property must be made good.

Causes and Prevention of Outbreak of Fire.

Prominence must be given to considering causes of fires, and means whereby such causes can be eliminated. Carelessness and ignorance are responsible for at least 85 per cent. of fires, and are most difficult to deal with when the class of labour in India is considered. Naked flames, such as oil lamps and candles, smoking, use of matches, etc., should be absolutely prohibited in or around buildings containing inflammable goods. Lights should be efficiently protected with wire or glass globes, especially where inflammable dusts are present. Friction is responsible for many fires in machinery; bearings should be frequently examined, and if inclined to heat, should be refitted, and properly lubricated with high flash-point lubricating oil. Hot-bearing indicators with alarm bell attached, which ring when a dangerous temperature is reached, are useful.

Gas Lighting.—Gas is comparatively safe, provided the burners are adequately protected, and not used when inflammable dusts are prevalent (unless dust-proof protection and anti-vibratory fittings are provided). Meters should be in well-ventilated positions, with an easily accessible cock to turn off the supply. All brackets should preferably be rigid, and the use of flexible tubing avoided. Gas-producers and attendant apparatus should be in a separate building in an open space.

Electric Lighting.—Properly installed systems are practically safe, and where fires due to electric lighting have occurred, the fault has usually been traced to poor workmanship and inferior materials, the use of which is unfortunately so large in Calcutta. Incandescent lamps generate a temperature sufficient to fire inflammable goods

such as celluloid, etc., and care should be used to prevent such materials coming into contact with incandescent bulbs. Flexible wiring is a prolific cause of fires, and should be avoided. Fittings connected by flexible wire should be without switches, so that the current is cut off from the flexible wire when the fitting is not in use. Where inflammable dusts or gases are present, dynamos, motors, resistances, etc., should be adequately protected, or situated in buildings away from the risk. The other fittings should be encased in dust-proof globes. Arc lamps should not be used in proximity to jute or cotton godowns, or where inflammable dust may accumulate. Electrical installations should be periodically examined by an expert, as the Indian climate rapidly deteriorates the insulation, as evidenced by the many recent fires in Calcutta due to this cause.

Improper Storage of Goods.—Many fires are caused by this. Acids require special care, and the carboys should be laid in lead-lined receptacles, which have a capacity greater than the contents of the carboy. The sun's rays have caused jute and rope fires, especially when focussed through windows, etc., which should be painted with at least one coat. Volatile liquids which give off inflammable vapours with a slight rise of temperature, require special care, as the vapour is liable to creep along the floor to a considerable distance until it comes into contact with a light.

Spontaneous Combustion.—Oily rags, waste, mops, sawdust, sweepings, metal turnings, filings, etc., have caused many fires spontaneously, and should be kept in metal receptacles, to be regularly emptied each night. Vegetable fibres are more dangerous than animal fibres, and oil (especially linseed) considerably hastens the action. Chemicals placed together will often fire spontaneously, and substances rich in oxygen should not be in contact with easily oxidizable materials. Chlorine gas in contact with turpentine or tarred ropes has caused fire; therefore care should be used in storing bleaching powder. Acids need particular care, nitric acid being especially dangerous when in contact with carbonaceous materials.

Inflammable Dusts.—The danger of fire and explosion due to these is shown by many explosions with great loss of life. Following two serious dust explosions in 1911, at a provender mill in Glasgow and an oilcake factory in Liverpool, Dr. R. V. Wheeler made tests with 66 samples of carbonaceous dusts collected from beams, ledges, or other projections. He divided the dusts into three classes :—

(1) Dusts which ignite and propagate flame readily, the source of heat to ignite them being small (e.g. a lighted match). These include sugar, dextrine (calcined farina), starch, cocoa, rice, meal, and sugar refuse, cork, unextracted and extracted soya bean, wood, flour, malt, oat husk, grain (flour mill), maize, tea, compound cake, grain (grain storage), rape-seed, cornflour (flour mill), chicory, briquette, gramophone records.

(2) Dusts readily ignited, but needing for the propagation of flame a source of heat of large size and high temperature (e.g. electric arc), or of long duration (e.g. flame of Bunsen burner). In this class are copal gum, leather, "dead" cork, cocoanut oil milling, rice milling, sawdust, castor oil, meal, oilcake, offal grinding (bran), grist milling, horn meal, mustard shoddy, and shellac composition.

(3) Dusts not propagating a flame under factory conditions, either because they do not easily form a cloud in the air, being contaminated with incombustible matter, or because the material does not burn rapidly enough. In this are organic ammonia, tobacco, spice milling, drug grinding, cotton seed, and soya bean, bonemeal, coal (foundry blacking), lamp black, sack cleaning, retort carbon, Russian rape-seed blacking, grain cleaning, charcoal (foundry blacking), brush carbon, stale coke, plumbago, bone, charcoal, and mineral and ivory black.

Dusts in (1) are arranged roughly in order of inflammability. Sugar, dextrine, starch, and cocoa are the most dangerous. In (2) the shoddy being of a fluffy nature, did not readily form a cloud, but contained enough fine material to render it dangerous when in bulk. Of (3) the first ten are all readily inflammable, but showed no signs of being able to propagate flame. Much depends

upon the fineness of the dusts. The lowest temperature at which sugar and dextrine dust will ignite is estimated to be 540° C. (1,004° F.), whilst the other inflammable dusts ignite at 600° to 650° (1,112° to 1,202° F.).

Petrol Storage.—Special regulations are necessary for the protection of garages, etc.

Defective Construction.—This has been the cause of many fires and also the means of fires spreading rapidly. In Calcutta, where heating is unnecessary, such fires are not so prevalent as in colder countries, but many do originate where chimney shafts are carried through floors or roofs and not properly protected.

Preventing the Spread of Fire.

Unprotected iron girders and columns are to be strongly condemned; they quickly buckle or collapse, often pulling down walls and buildings. Steel and wrought-iron lose strength at high temperatures, and may depreciate 75 per cent. before red heat, so that buckling results, especially if no space is allowed for expansion. Cast-iron is particularly *bad;* it fails suddenly, especially if water is directed upon it when heated. All constructional iron work should be protected by at least 2½ to 3 inches of concrete.

A danger in India is the use of inferior mortar which disintegrates rapidly when exposed to heat. Good well-burnt bricks, well-bonded and flushed with mortar, form excellent walls, better than stone, which cracks when suddenly cooled and disintegrates when heated. Sandstone is best for withstanding fire, but is much inferior to brick walls. The fire-resistance of stone varies considerably with the method of quarrying, and granite can be quarried in such a way as to offer 100 per cent. more resistance.

Reinforced concrete is really good when proper precautions are taken in the preparation and use of the concrete, as, owing to the low thermal conductivity of good concrete, heat requires a considerable time to penetrate it to any degree.

Sprinklers.—Sprinklers are the best means of preventing serious fires, especially in warehouses containing jute, cotton, etc., and materials which produce a flash fire. By no other means can water be delivered at the seat of fire so accurately and promptly. The water in the sprinkler pipes, when in circulation, automatically rings an alarm bell and takes the place of a watchman. Sprinkler heads are made to operate at various temperatures, the most usual being 155° F. Where used over boilers, in dry kilns, etc., they operate at about 286° F., and in buildings where very high temperatures exist, the point is as high as 366° F.

The nozzle of a sprinkler head is usually about ½ inch in diameter, and the discharge per head approximately 17½ gallons per minute at 10 lb. pressure, 30 gallons at 30 lb., and 58 gallons at 100 lb. The efficiency at 50 lb. pressure is more than double that of the same sprinkler at 20 lb. per square inch. In buildings where there are acid and corrosive vapours, sprinkler heads should be examined frequently, as the fuse-bar may be coated over, and raise the temperature of operation.

Two independent water supplies for the sprinkler system are preferable, also an inlet to which the pumps of the Brigade can be attached. The bottom of elevated tanks should be at least 20 feet above the highest sprinkler head, and the supply pipe should project 4 inches into and above the bottom of the tank to be clear of sediment. A 10,000 gallon tank may be used for medium size plants.

Automatic Fire-Alarms. — Usually "detectors" are placed throughout a building at intervals, and connected to an indicator board, in its turn connected to the Fire Station. At a fixed temperature contact is made at the "detector" or thermostat, the position of which is shown on the indicator board. In the "Mercurial thermostat" a platinum wire is inserted in a tube similar to a barometer. The wire is placed at a point in the tube higher than that to which the mercury usually rises, and when an abnormal rise takes place, the alarm is electrically transmitted by the mercury-platinum contact. Metallic thermostats depend upon

the differing co-efficients of expansion of various metals. In one type of Automatic thermostat the expansion of air in a sealed chamber causes this to bulge and close the circuit. Some, such as the Fox-Pearson detector of Colonel Fox of the London Salvage Corps, are arranged so that a cautionary alarm is given to notify sudden rise of temperature, which, if maintained, develops into a fire call. In the May-Otway system the detectors notify a rise in temperature, being adjusted automatically by a compensating balance at the ordinary temperature. A detector adjusted for a 25° rise will give the alarm at 105° when the normal temperature is 80°. For climates with very variable temperatures, this system is worth consideration.

The Aero Fire Alarm on the pneumatic principle consists of a small copper pipe $\frac{1}{10}$-inch diameter, the ends being carried to the indicator board. The detector consists of a flat circular chamber which bulges and forms electrical contact when the air in the copper tube expands. A valve allows for compensation for normal temperatures, thus any slow rise is automatically allowed for, but a sudden rise operates the system.

Fire-resisting Doors.—Iron and steel doors are not satisfactory, being liable to buckle badly in fires unless specially protected. A door by Messrs. Mather and Platt consists of three thicknesses of $\frac{7}{8}$-inch boards at right angles laid diagonally, and completely encased in tinned steel or iron sheets 20 inches by 14 inches by 26 S.W.G. thick. The joints are lock-jointed and form a hermetically sealed casing. The door is hung on an inclined bar by two pulleys, so that it tends to remain closed.

Partitions.—Dividing walls of at least 9 inches brickwork form an excellent fire stop, and reinforced brickwork, 3 inches thick, with reinforced mesh in the horizontal joints laid in cement mortar, is also good.

Fire-resisting Floors.—Insurance Companies consider an approved fire-resisting floor to be equal to a fire wall, and the premiums are based accordingly. This should be noted when building.

Fire-resisting Glazing. — Two reports by the British Fire Prevention Committee show the utility of this. In one case the glazing when used vertically in windows withstood a temperature rising to 1,500° F. for 90 minutes followed by a stream from a fire-engine, and when used horizontally it withstood a similar temperature for one hour, followed by a similar jet of water. The maximum temperature attained was 1,600° F.

Protection of Openings in Walls.—Holes through which belts pass should be specially protected.

FIRE APPLIANCES SUITABLE FOR USE IN FACTORIES, MILLS, ETC.

Buckets.—Buckets filled with water or sand have the advantage of combining some efficiency with considerable economy, and are necessary to all installations, and in many risks are sufficient in themselves. An official should be held responsible that all buckets are kept filled, and that none are missing. It is a good plan to red paint the wall behind the positions of the buckets or other portable appliances to enable an Inspector to see at a glance whether they are in their places. It is found that fire-buckets are often used for purposes other than fire-extinguishing, *e.g.* window-cleaning, etc., and not replaced. Therefore all *fire*-buckets are better to have rounded or conical bottoms, so that they must remain in their proper places. But to reach a fire a small jet, if available, is better; therefore for every set of buckets a small double-acting hand-pump should be provided. By means of a stirrup one man can work the pump whilst directing a continuous stream of water.

Corridor Pumps.—These are tanks fitted with pumps and mounted on wheels, and hold about 30 gallons of water; the pump can project a small stream about 30 to 40 feet.

Chemical Fire Extinguishers.—There are many efficient types available for attacking a fire in its early stages; they combine the double effect of water and of carbon dioxide and salts. The general

principle is the generation of CO_2 by the combination of alkali (usually bi-carbonate of soda) with an acid (usually sulphuric). The alkali is mixed with water in the cylinder, and rapid generation of the CO_2 causes a pressure which expels the contents in a stream to a distance of 15 feet to 20 feet. Theoretically 1 lb. of bicarbonate of soda requires $9\frac{1}{2}$ oz. of sulphuric acid to liberate all the gas, but it is not advisable to use so much. The maximum quantity of acid per 1 lb. of bicarbonate should not exceed 6 oz., and about $\frac{3}{4}$ lb. of bicarbonate is required for 2 gallons of water. In most cases the acid is contained in hermetically sealed glass bottles, which are broken as required either by a plunger or by concussion. In others the acid is in a lead bottle sealed with a lead ball, such that when the extinguisher is inverted the ball drops and the acid is liberated. In others the acid bottle is sealed with a thin sheet of lead held in place by a screw collar, the acid being liberated by puncturing the sheet with a pricker. If the bottle is not hermetically sealed, there is danger that the sulphuric acid may combine with moisture, and if it is left unattended too long, the acid becomes weak and useless. The acid also combines with the alkali in the water generating CO_2, so that if the outlet of the extinguisher is closed an explosion may result.

Portable Fire Extinguishers should be tested to 350 lb. per square inch, and the capacity should not exceed 3 gallons or be less than 1 gallon.

Chemical Machines, etc.—These are specially for dealing with fires of volatile liquids and electric arcs. One containing carbon tetrachloride having SO_2 and CO_2 gases in solution has been thoroughly tested by the British Fire Prevention Committee. The contents when expelled extinguished an arc of 250 amperes at 200 volts. In tests on burning petrol, success was obtained in cases where the fumes could be collected and thus exclude oxygen from the fire.

Sawdust.—Sawdust as a fire extinguisher has advantages over sand, because of its blanketing action. Sand, being heavy, sinks to

the bottom, but sawdust floats on the top and excludes the oxygen. Moreover, sand gets into the bearings of machinery. Its efficiency is greatly increased by adding 10 lb. of bicarbonate of soda to one bushel of sawdust. An addition of 10 per cent. of iron ore prevents the bicarbonate of soda from caking. Dry sawdust is as efficient as damp sawdust; the latter should not be stored owing to the possibility of spontaneous combustion.

Bunker Fires.—For the prevention of bunker fires in ships, Professor Vivian Lewis suggested that cylinders containing highly compressed CO_2 gas be inserted into the coal, the cylinders to be fitted with fusible plugs, fusing at a comparatively low temperature. Before any accumulated heat becomes dangerous, the gas would be rapidly liberated and cool the coal. Should a fire have started, the gas would extinguish it. This principle could be applied to jute and cotton godowns.

Hydrant Services.

A vital point in successful fire-fighting is to have sufficient pressure at the nozzles. The following are the maximum pressures that can be used efficiently with nozzles of various diameters:—

Diameter of nozzles . .	$\frac{1}{2}$ inch.	$\frac{5}{8}$ inch.	$\frac{3}{4}$ inch.	$\frac{7}{8}$ inch.	1 inch.
	lb.	lb.	lb.	lb.	lb.
Maximum pressure that can be used with advantage .	70	87	104	121	139

More efficient work can be done with one stream at good pressure than with several jets at low pressure, at the same time unnecessary water damage is avoided.

Where the supply is from gravity tanks, there is often difficulty in obtaining sufficient head for the hydrants on the upper floors; this may be overcome by installing "Augmentor" pumps in the mains where the pressure is low, worked by hand or power.

The size of the mains depends upon the length, number of outlets, quantity of water required, etc., but 4 inches should be the minimum diameter with 3-inch offsets for connections to hydrant valves. A good plan is to lay the mains completely round a building, and it should be fed by two supply pipes from the pump. Valves should be fixed at intervals, so that should the main burst or be damaged this portion can be isolated without interfering with the whole service. When valves are not provided it is well to have at least two plugs of wood available, so that the broken ends of a main can be quickly and securely plugged. With hydrants and fittings simplicity and speed in getting to work are the important features.

Unlined canvas hose $2\frac{3}{4}$ inches in diameter is very satisfactory, but where water may cause damage by sweating through the canvas before this has expanded, hose lined with rubber can be used. Nozzle orifices usually vary from $\frac{1}{2}$ inch to 1 inch in diameter. Care should be taken that they are not damaged, and that the orifice is a perfect circle, for the slightest flaw causes the jet to break into spray, thus considerably reducing its value.

Fire Brigade Appliances.

A "First Aid Appliance" consists of a motor chassis of about 14–20 h.p., on which is mounted a cylinder containing about 50 gallons of water, connected to which is a carboy of highly-compressed CO_2 gas. This provides the pressure for expelling the water through a reel and hose. The jet is immediately available on arrival at the fire, and the crew get to work in a few seconds. The nozzle orifice of these machines is about $\frac{1}{4}$ inch in diameter, and the quantity of water is sufficient to extinguish a very large percentage of fires completely, without the aid of the pumps of the more powerful machines. "First Aid Appliances" often carry hook-ladders and ropes for rescue work, also gear to get to work from street hydrants.

Efficient respirators are of two classes, the "Self-contained Breathing Apparatus" and "Smoke Helmets (Bellows type)." The

former renders a man independent of the outer atmosphere. On the fireman's back are two cylinders of oxygen, and in front is a regenerating bag. A mask is fitted over the nose and mouth, and is connected to the regenerating bag by two tubes fitted with valves, one to allow the breath to enter the bag without returning, and the other *vice versâ*. As the man exhales, the breath passes through caustic potash in the bag; this extracts the CO_2 from the breath. At a point near the inhaling tube the oxygen is admitted, kept at 30 per cent. by means of a regulator, and thus allows the fireman to work hard in comfort.

The Smoke Helmet consists of an asbestos helmet strengthened at the top to protect the head. Air is pumped into the helmet through specially armoured air-hose by double-acting bellows. No valves are fitted, as the air flowing into the helmet and escaping through a joint near the ears, effectively prevents the entry of smoke or foul gas. The radius of work is of course limited by the length of air-hose, which may become entangled in *débris*, or damaged by falling walls.

Almost all fire-escapes and ladders are telescopic, the extension being made by a hand-winch and steel rope. The height of the fire-escape when extended varies from about 35 to 70 feet. When carried on the rear of a motor chassis, unshipping can be effected in a very few seconds, and the escape can be got to work in considerably under one minute.

Turntable ladders are superseding wheeled fire-escapes; their advantages are that they can be used at almost any angle independent of the support of buildings, and they can also be swung round in any direction. Small space is required for working; a street wide enough for the chassis is sufficient for operating the ladders. A small two-cylinder CO_2 engine is used for extending the ladders to the full height of about 80 to 100 feet.

Buildings have to be scaled and rescues effected in positions where it is impossible to approach with turntable ladders or ordinary fire-escapes, such as the rear of buildings, which can only be reached through narrow passages. In such cases hook-ladders are used. These are usually made of best selected straight grained

English ash, and are about 13 feet 5 inches long. At the top is a steel hook 2 feet 2 inches long, with a 6-inch spur at the end. The under side of the hook consists of eight jagged teeth. The weight of ladder and hook complete is about 24 lb.

Turbine and reciprocating pumps are both used; the latter enables the water to be lifted from below the pump without priming, and the most effective high-pressure streams can be obtained at slow engine speed.

For the turbine pump an auxiliary priming pump, usually of the reciprocating type, is fitted, and is very efficient in getting the turbine to work.

The prevention of unnecessary water drainage is an aim of every well-trained fireman, and is facilitated by the use of turbine-pumps, since with these and hand-control nozzles, the branch-pipe man can turn off the water without having to communicate with the engineer at the pump. Although relief-valves are fitted on reciprocating pumps, making the use of hand-control nozzles possible, the method is not so satisfactory. Both types of pumps are driven by the propelling petrol engine, the turbine being connected direct to a shaft from the gear-box, and the reciprocating pump driven by pinions and a silent chain. The pump is usually placed at the rear of the chassis, but a recent petrol-driven engine has the pump just behind the driver's seat.

Motor Garages.

The Author concluded his Paper by suggesting various precautions for fire protection and prevention for motor cars and in garages, of which the following are the principal points. Petrol gas is $3\frac{1}{2}$ times heavier than air, and therefore the greatest danger is near the floor, or in motor pits, etc. The collection of vapour is difficult to detect and needs a constant look-out. All garages should be sufficiently ventilated. One pint of petrol will make 200 cubic feet of air highly explosive, the most dangerous proportion being one part of petrol vapour to eight parts of air. Petrol vapour creeps along the ground, and many fires and explosions

have been caused by it coming into contact with a light very many yards away from the point of leakage or escape from an open tank. Spilled petrol should be immediately wiped up. In fires the effect of water is to spread the flames, and sand or preferably sawdust should be used, the efficiency being greatly increased by adding 10 lb. of bi-carbonate of soda per bushel of sawdust.

One sawdust bin about 2 feet 6 inches by 1 foot 6 inches by 2 feet 3 inches high, with doors at the bottom extending the full length, should be added for every 1,000 square feet.

AUTOMATIC AND SEMI-AUTOMATIC MACHINE-TOOLS.*

By C. WARREN BOULTON, of Calcutta.

[*Selected and Abridged for Publication.*]

The importation into India of machine-tools was until recently confined exclusively to the ordinary type of engine lathes, drills, planers, slotters, etc., for the numerous repair shops of the railways, shipping companies, mills, and engineering firms. Recently, several firms have realized that India has a big future as a manufacturing country, and have prepared for the production of machine parts and accessories in quantities, thereby opening up the introduction of modern machine-tools specially designed for repetition work.

Government factories, such as the Ordnance, Telegraph, and Instrument Factories, where work of very high accuracy is produced in large quantities, have also brought before engineers in India the possibilities of automatic and semi-automatic machines, whilst the extensive enlargements of railway works have led to the introduction of similar machines.

The great objection raised against the installation of high-class machine-tools in India is that of labour, as the Indian mistri cannot compare with the British machinist, but the economies

* This Paper was read and discussed at a Meeting of the Calcutta and District Section on 15th December 1915. A copy of the complete Paper may be borrowed from the Institution Library.

effected by high-speed tools are just as great in India as in Great Britain, and automatic and semi-automatic machine-tools, by tending to eliminate the human element, increase rather than decrease their value in a country where the labour question is so difficult. A further reason why the introduction of up-to-date tools has been hampered is the distance from Europe, and until recently it was practically impossible to obtain either high-class machine-tools from stock in India, or sound advice on which an indent could be based. The consequence was that the purchase of new tools was usually left to the discretion of London agents who usually on insufficient knowledge bought in the cheapest market, the works managers themselves having had no chance of submitting samples of work or of consulting with the machine-tool makers regarding the work to be produced.

Turret Lathes.—These semi-automatic tools form a very important part of the equipment of railway and other workshops. When first introduced, about ten years ago, workshop managers doubted whether it was economical to turn such articles as motor-pins and bolts direct from the bar, as considerable material was thereby cut to waste. It is now, however, generally accepted that the most economical method is to make such articles from the solid bar. The following figures taken from the actual cost sheets of a large Railway Workshop are interesting :—

100 *Sample Loco. Spring Pins.*

Cost of Material . .	Rs.	29	4	0	Cost of Material . .	Rs.	30	0	0
Forging	,,	12	2	0	Turning on Hexagon Turret Lathe . .	,,	13	8	0
Centring	,,	0	12	0					
Turning on Centres .	,,	16	12	0					
Total . . .	,,	58	14	0	Total . . .	,,	43	8	0

In justice to the hexagon turret lathe, it must be pointed out that the labour cost of Rs. 13 8 for turning the hundred spring pins in question is enormous, and proves that the machine was being run far below its maximum capacity, as is usually the case with machines of this type in India. The use of this lathe obviates

the complex and wasteful procedure associated with the engine lathe producing work from forgings; the (finished) work is produced from the raw material at one effort, on one machine, by one man, at one cost, easily controlled, and with very little waste or loss of time, so that the workshop organization becomes simpler and the cost of production is reduced. Bar steel costs about one anna per pound, whereas forgings cost three to four annas, so that even if the weight of material cut away when working the bar is three times that obtained when machining forgings, the question of economy is not affected.

Hexagon Turret Lathes.—These lathes are suitable for handling long or short work, whilst the tools are easily adjusted and the chuck jaws and screwing dies are so quickly changed that it is economical to make either one or two or a large number of articles at one setting, so that the machine is well adapted for the requirements of either repair or manufacturing work.

The Roller Steady Turning Tool, by which the heaviest reductions in diameter can be made at high periphery speed with a coarse feed, is quite recent, and has effected an astonishing increase in the production of the lathe. Previously the steadies employed were of the flat or friction type, but it was found that when high-speed cutting tools were used, the high surface speed of the work, combined with the pressure at the point of contact with the steadies, rapidly destroyed the face of the latter, causing bad finish to the work, and the limit of production was therefore the speed at which the steady would stand. This tool eliminates all friction at the point of contact with the work, and places the limit of output with the cutting tool, which removes metal four times as fast as with the flat steady tool. The cutter is mounted in a steel slide, which can be moved in and out by means of a knurled wheel, a sensitive stop arrangement enabling the cutter to be withdrawn from the work, and returned any number of times with a certainty of producing exactly the same diameter.

The following particulars of some speeds and feeds for cutting

mild steel of about 30 tons tensile strength, using high-speed tools in the roller steady turners, are from actual tests, the net H.P. consumed by the machine at each cut being carefully measured. A double belt was used for driving the machine.

Reducing from	A bar to	Turns per Minute.	Cuts per Inch.	B. H. P.
Inches.	Inches.			
3½	1½	122	44	13·48
3½	2	182	56	12·55
3½	2½	222	56	12·27
3	1½	182	56 .	11·28
3	1½	174	44	11·79

Hexagon turret lathes are well adapted for machining locomotive stay-bolts, the threading being done by two die-heads set tandem fashion, both ends of the stay being screwed simultaneously. The following figures may prove of interest:—

Made from	Diameter of Thread.	Pitch of Thread.	Length of Staybolt.	Actual time.
	Inches.		Inches.	Min.
Bar . . .	1¼	11	9	3
Forging . .	1¼	11	9	4
Bar . . .	1¼	11	24	4
Forging . .	1¼	11	24	6
Bar . . .	1¼	11	36	5
Forging . .	1¼	11	36	7

Combination Turret Lathe.—This tool is fitted, in addition to the main turret, with a chasing saddle, enabling threads to be cut with speed and accuracy. Provision is made for cutting right or

left hand screws, the leader being reversed by a lever on the feed-box, and the nut is connected with the tool-slide in such a way that when it is withdrawn from the leader by the hand-lever on the saddle, the tool or chaser is simultaneously withdrawn from its cut, and *vice versâ*, without either turning the screw, or moving it endwise.

The pilot wheel automatically comes out of action when not in use, so that when the quick power motion comes into action the pilot wheel is stationary, and the operator is quite free from the danger of revolving arms or handles. The lathes may be fitted with draw in chucks with automatic bar feed and either three jaw self-centring or four jaw independent chucks.

The application of turret lathes to the production of locomotive details in the handling of cast-iron and wrought-iron piston-heads, cast-iron valves, spindle guides, and wrought-iron buffers and casings, is shown in the following notes.

In the case of a wrought-iron piston-head 19 inches diameter, one of the standard type now used on express locomotives, a large amount of metal is removed from the outside, whilst the hole is bored from the solid.

The time taken to finish this job by the methods described is 2 hours 20 minutes, actual cutting time, not including putting the job in the chuck or setting the tools.

The main turret is inclined at an angle with the bed to enable long bars to clear the supplementary square turret.

The operations are:—

1. Rough Forging, gripped in three-jaw chuck, is centred by means of the short stiff centring tool in the turret.

2. Hole is then drilled with a high-speed twist drill.

3. Rough bore the hole taper with a flat high-speed steel-tool stepped to break the chips, whilst at the same time the counterbore is roughed out by the single point cutter in the boring bar, the end of the bar being supported in the hard steel steady bush in the chuck.

4. The counterbore is finished by a flat steel form cutter carried in a similar bar on the next turret face.

5. The taper hole is finished by means of a left hand spiral taper reamer, an excellent finish resulting.

6. The front web of the piston is rough faced with a high-speed steel-tool in the square turret.

7. The outside diameter is rough turned as far as the chuck jaws with a high-speed tool interchanging with that used for facing the web. These tools are fitted with locating screws so that they can be replaced in exactly the right position.

8. The outside diameter is finished turned.

9. The whole of the web is finished by the broad shaping tool carried in a cast-iron holder, bolted to the turret, the tool-holder being steadied by a bar which fits into the steady bush in the chuck; a perfectly smooth surface is produced by this tool owing to its rigid support.

10. The groove for ring is rough turned.

11. The groove for ring is finished turned.

After a number of pistons have been finished in this manner, a set of soft jaws are placed in the chuck, and are skimmed up in position to ensure them holding perfectly true. The partly finished pistons are then gripped by the previously machined part, and the remaining operations consist of rough-facing the boss and web from the square turret, following the outline of the forging, and finishing same with another flat tool carried in the same holder as used previously.

Each tool is controlled by an automatic and dead stop so that after the first piston is made and the tools set, no further callipering is required.

The tools used consist of two point cutters carried in holders of various kinds.

Capstan Lathe.—This is ideal for small and medium size repetition work from bars, castings, or stampings, as it is furnished with a draw-in chuck for bar work and a three jaw chuck for castings or blanks. It has automatic feeds and stops, whilst the chasing saddle is operated along the bed by a rack and pinion, and has eight adjustable stops, four transversely and four longitudinally.

By the use of these stops two dimensions in either direction can be produced with the same tools. A square turret for the cross-slide is supplied for chuck work where a large number of operations are required. The roller steadies on this lathe are of the inverted type, this construction allowing a perfectly free passage for the chips. The chasing gear is similar to that of the combination turret lathe previously described.

Full Automatic Screw-Machine.—These machines are now found in engineering works of all classes dealing with a large variety of articles from small screws up to locomotive hand-rail pillars, large bolts and nuts, etc. A standard machine is practically an ordinary capstan lathe with the addition of a horizontal shaft, carrying drums and disks to which cams are attached. The latter operate the various parts of the machine, and render it automatic. The drum carries two sets of cams, the one for opening and closing the chuck, and the other for advancing and withdrawing the feed-collet which moves the bar. The cross-slide is operated in either direction by back and front levers pivoted on the frame, and moved by cams on either side of the disk on the cam-shaft.

When the machines are intended to deal with general work they are fitted with a standard set of cams, which, in addition to chucking and feeding the bar, provide for the following operations: starting (for turning or drilling) centring, or centring and facing; rough turning or drilling, or turning and drilling at the same time; finished turning or reaming, or both at the same time; supporting work for forming; forming in the cut-off side; screwing or tapping; cutting off, by a tool fixed in the back of the cut-off side, the tool being frequently made with a step, so as to reduce the end of the bar while the finished piece is being cut off.

The foregoing includes every operation necessary to produce any ordinary objects from a bar, and the whole range is covered without any alteration to the cams. The automatic screw-machine is capable of very general application, and given a sufficient quantity of repetition work, it may be economically employed in all classes of engineering work. The operations of an automatic machine

are continuous, and not subject to the temporary stoppages which reduce the output of the hand worker, whilst the services of one skilled operator can be distributed over a number of machines. On suitable work, an automatic screw-machine occupies less than one-sixth of one man's time, so that in many cases it can be run in the spare time of the workman on another machine, the product being obtained practically for nothing in the form of labour charges.

Hexagon and square head screws are turned from the round bar, the heads afterwards being milled to shape. This has the double advantage of being cheaper than turning the screws from drawn hexagon or square bar, saving the waste of expensive material, and permitting the use of a better grade of steel, the drawn bar being somewhat weak in the centre.

Mention may be made of the Automatic Stud Machine with magazine attachment for second operation, by means of which the half finished studs are fed automatically through the chuck; also of the Automatic Copper Stay Machine, on which copper stays can be produced accurately with great rapidity, for example, a $5\frac{1}{2}$ inch by 1 inch diameter stay is produced in 1 minute 30 seconds, including the turning away of the central portion, shorter or longer stays being produced in proportionate times.

The Automatic Condenser Ferrule Machine was designed specially for producing ferrules for surface condensers from brass tube. Ferrules $\frac{7}{8}$ inch diameter and 1 inch long have been bored, screwed, chamfered and cut off at the rate of 14 per minute, an output equal to 8,000 per day, of ten hours.

The Automatic Turning Machine is on generally similar lines to the screw-machine, in which all operations are automatic except chucking, the machine stopping automatically at the conclusion of work. Just, as much work is being regularly done on engine lathes which ought to be done on turret lathes, so, much work is done on turret lathes which ought to be done on automatic turning machines. The following is a comparative statement taken from actual practice in a works where a very large number of both turret lathes and automatics are employed. The reductions in price, consequent on

Automatic Turning Machines.

Cost of Operations.

PIECE.	Previously done on	Now done on	Number of Operations.	Previous Price.	Present Price.	Remarks.
Conical Holder (No. 2 Hex.) .	No. 5 Caps.	No. 2 Auto.	2	$6\frac{1}{4}d.$ each	$2\frac{1}{2}d.$ each	Steel.
Guide Pulley (B. B. Drill) $4\frac{1}{2}$ inches diam. × $3\frac{3}{4}$ inches wide; crowned and bored $1\text{—}\frac{5}{16}$ inch . . .	do.	No. 2 Auto.	2	$7d.$,,	$1\frac{1}{2}d.$,,	C.I.
Pump Pulley—3 inches diam. × $\frac{7}{8}$ inch between flanges; crowned and bored . .	do.	No. 2 Auto.	2	$3s.\ 6d.$ per dozen	$4\frac{1}{2}d.$ per dozen	C.I.
Sleeve (B. B. Drill) $1\frac{1}{2}$ inches diam. × 5 inches long .	No. 4 Caps.	No. 2 Auto.	2	$5d.$ each	$1d.$ each	C.I.
Gland for Pump— 1 inch diam. × $\frac{3}{4}$ inch long	No. 4 Caps.	No. 2 Auto.	1	$2s.$ per dozen	$3d.$ per dozen	C.I.
$1\frac{1}{8}$ inch diam. × 1 inch long		No. 2 Auto.	1	$2s.\ 6d.$ per dozen	$4d.$ per dozen	C.I.
Chuck Body (12 inches) . .	Comb. Turr. Lathe	No. 10 Auto.	2	$3s.\ 8d.$ each	$4d.$ each	C.I. finished all over.

the transference of the above work from capstan or turret lathes to automatic machines, are enormous.

[In the original Paper full descriptions of various tools were given. These included combination turret lathes for machining locomotive piston heads, cast-iron valves and railway buffers and other machines. The complete descriptions are too long for the space at disposal in the Proceedings.]

THE MANUFACTURE OF OXYGEN AND ITS USE FOR WELDING AND METAL-CUTTING.*

By J. M. CHRISTIE, *Member*, of Calcutta.

[*Selected and abridged for Publication.*]

Until 1905 all the oxygen gas used in the United Kingdom was produced chemically. In that year a plant was installed in Birmingham whereby oxygen was manufactured mechanically through the liquefaction of air. The new method rapidly superseded the older, and large plants were erected in British engineering centres, and, more recently, in Calcutta, Bombay, Shanghai, and other Eastern ports.

In the production of oxygen mechanically, the result depends upon a certain amount of refrigeration, produced by the expansion of a gas which has been cooled, and intensified to the point of liquefaction. If liquid air is evaporated the nitrogen volatilizes more quickly than the oxygen, and the remaining liquid becomes richer in oxygen.

Air is drawn through a tank of slaked lime to purify it, then is compressed by powerful pumps, dried, cooled, expanded, liquefied, and disassociated into nitrogen and oxygen. The nitrogen, after helping to cool further supplies of air to liquefaction, is returned

* This Paper, based on publications of the British Oxygen Co., was read and discussed at a Meeting of the Calcutta and District Section on 19th January 1916. A copy of the complete Paper may be borrowed from the Institution Library.

to the atmosphere. Air enters the first stage of a compressor and is delivered through water-cooled coils before passing through three more stages, being cooled between each. When the compressor is first started, the final delivery pressure is 2,000 lb. per sq. in., and the expansion pressure beyond the regulating valve 5 lb. per sq. in., but after liquefaction the normal working pressure during the separation of the oxygen and nitrogen falls to about 700 lb. per sq. in. and the expansion pressure to 3 lb. per sq. in. The air, at high pressure, is then delivered through bottles containing calcium chloride and thoroughly dried (to obviate the freezing of moisture and consequent obstruction of the separator coils, etc.), and enters the forecooler to be cooled in a refrigerating machine by means of ammonia or CO_2. From a forecooler this high-pressure air, at much lower temperature, is passed through pipes in a separator, and being further cooled by ascending waste nitrogen and distilled oxygen, is liquefied. It then falls into a receiver, where the nitrogen, evaporating during its progress to the atmosphere, gives up its cold to the on-coming compressed air, and assists liquefaction. The liquid oxygen, during evaporation and on its way to the gas-holder, also gives up its cold to the on-coming air. As liquefaction takes place, and the interchange of heat and cold continues, the normal process becomes automatic, and terminates with a final delivery pressure of about 700 lb. per sq. in. and an expansion pressure of 3 lb. per sq. in. The oxygen passes into a gas-holder, and is then compressed by pumps to 1,800 lb. per sq. in. into steel cylinders. The standard cylinders for welding work are of 100 c. ft. and 200 c. ft. capacity, but smaller cylinders of 40 and 20 c. ft. capacity are employed for other purposes. All cylinders are subject to the rules of the Indian Government and of the Indian Railway Board. They are annealed every three years and tested annually to a hydraulic pressure of $1\frac{1}{2}$ tons per sq. in. for 1,800 lb. working pressure. A permanent stretch of not more than 10 per cent. is allowed.

Oxy-Acetylene Welding.

In 1899 the late Mr. Thomson Fletcher, of Warrington, showed that, after heating an iron plate to incandescence by means of an

oxygen and coal gas blow-pipe flame, it was possible, by largely increasing the oxygen, to "fuse" holes in the plate. Later the same process was applied to the opening of tuyeres in blast-furnaces which had become blocked by the solidification of metal. These operations paved the way to the present-day blow-pipes.

In oxy-acetylene welding on the high-pressure system the two gases enter the blow-pipe under pressure; oxygen from a standard cylinder and acetylene from a cylinder in which it is dissolved in a porous material soaked in acetone. This gives a portable system which is specially applicable to work on board ship, in boilers and confined spaces, and also for cutting away iron structures to get quick access to the seat of a fire.

In the low-pressure system oxygen only is supplied under pressure and acetylene from a generator in which the carbide should not be decomposed too rapidly, to avoid great heat. For example, a "water on carbide" generator, with a capacity of 20 lb. of carbide, should be regulated so as to run 5 hours and generate without recharging about 90 feet of acetylene.

The purification of acetylene is highly important. It is first washed by bubbling through water, and then passed through a filter of felt to remove traces of lime dust which, passing through the blow-pipe, would injure the weld. Other impurities are removed by passing through a purifier containing heratol,* which should be changed after about 110 c. ft. of acetylene per pound have passed through it.

Oxy-acetylene welding does not supersede ordinary forge welding where such is applicable, but the portable blow-pipe can be used in confined spaces on difficult work as a substitute for riveted or brazed joints. Theoretically $2\frac{1}{2}$ volumes of oxygen are required for the complete combustion of one volume of acetylene, but in practice the best welding results are obtained with $1\frac{1}{2}$ volumes of oxygen

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* The Oxy-Acetylene Illuminating Co. define "Heratol" as "Kieselguhr impregnated with chromic acid." *See* also Manly ("Oxy-Acetylene Welding and Cutting,") "a solution of chromic or sulphuric acid absorbed in porous earth."

to 1 volume of acetylene. The flame has in its centre a small white cone, at the apex of which the temperature is about 6,000° F., and consists almost entirely of CO, which is being converted, at its extremity, into CO_2. Round the flame is a relatively cool jacket of hydrogen, which, not being able to combine with oxygen at the very high temperature in the immediate neighbourhood of the flame, remains temporarily in a free state, and thus protects the inner zone from loss of heat.

Autogenous welds can be made without injurious effect upon the metal. Bars of Staffordshire iron welded together by this system gave tests over 29 tons per square inch at the joint, while welded plates of iron and steel, varying in thickness from 20 gauge upwards, have proved stronger at the joints than in the body of the plate.

The speed at which work can be welded varies with its nature. In the following Table is given the speed per hour on iron plates:—

	Inches.	Inches.	Inches.	Inches.
Thickness of plate . .	3/64	1/8	3/8	1/2
Foot-run per hour . .	30	14	6	4

The above were obtained when working on cold plates. By pre-heating near the parts to be welded in $\frac{1}{4}$ inch plates and upwards, the time and cost can be reduced.

In welding cast-iron, especially thin sections, it is necessary to pre-heat the castings slowly to a dull red, to weld while in this condition, and then to allow slow cooling. In this way shrinkage strains will be equalized or reduced and cracks avoided. The welding of cast-iron is more uncertain than steel or wrought-iron, and at welding temperature it is not so easily worked, as it is not so plastic. Preliminary heating and subsequent slow cooling in a muffle are most important, especially in light intricate castings, such as motor-car cylinders. Before the advent of this process, cracked motor-car cylinders or jackets were almost invariably scrapped. Now, complicated defects may be repaired, but delicate work demands considerable experience. Expensive renewals are often saved at a small repair cost. The process is particularly applicable

for light machine castings, but is not recommended for the repair of heavy iron castings.

Ferro-silicon sticks should be used as feeders in cast-iron welding. A suitable flux (boracic acid, 80 parts; powdered chlorate of potash, 20 parts; and Fe. carbide, 15 parts) should be applied after the iron has been raised to a good red heat.

The conductivity and consequent dispersion of heat in the welding of copper detract from the economy of the weld. The process is often employed, but chiefly on light work. Malleable-iron and cast-steel may be welded in the same manner as cast-iron, but welds in the former are not, as a rule, very satisfactory.

In boilers, welding may be substituted for chain riveting or stud patching of cracks in furnace; landing edges may be built up, manhole doors made good, cracks or corrosion near rivets repaired, tube-plate repaired, etc., and there is a wide scope for the oxy-acetylene flame in boiler repair work.

Metal-Cutting.

Oxygen is regularly used for cutting wrought-iron and steel structures. A jet of oxygen directed upon a previously heated spot of metal ignites it, and the metal acting as its own fuel burns away rapidly in the form of iron oxide, which, formed at a comparatively low temperature, lacks fluidity. It was difficult to eliminate all the oxide, as much adhered to the partially molten metal, preventing the intimate contact of metal and gas; the result was that combustion soon failed and the cutting operation was impeded. The process was intermittent, the consumption of oxygen wasteful, and the cut wide, coarse, and irregular.

In 1904 a new cutting blow-pipe solved this difficulty. It consisted of an ordinary blow-pipe, with an additional passage through which an independent and separately controlled stream of oxygen was supplied at the will of the operator. This supply could be discharged through the centre of the blow-pipe, the mixed gases employed for heating being conducted through an annulus surrounding it; alternatively the supply could be brought through

a passage immediately behind the heating flame. The expedient of maintaining an independent heating jet in operation whilst the cutter is travelling renders the cutting continuous.

The edge of the plate at the point to be cut is first heated by a mixed jet of oxygen and suitable fuel gas. When this spot is incandescent, a fine cutting jet of oxygen is discharged upon it and produces combustion with the formation of iron oxide. The jet of oxygen is made sufficiently strong to blow away this oxide in front of it, and a clean narrow cut is made at a speed comparable with hot sawing. The metal on each side of the cut is neither melted nor injured, as the action proceeds too rapidly for the heat to spread.

The following examples of good average cutting are from experiments with a hand oxygen cutter which was only altered as required for the gas-pressure corresponding to the thickness of the plates.

Thickness of plate. Mild Steel.	Foot-run of metal cut per hour.	Total quantity of Oxygen consumed per hour.	Pressure of Oxygen supplied to cutter.
inch	feet	cubic feet	atmospheres
$\frac{1}{2}$	60	60	2
1	40	90	2·5
$1\frac{1}{2}$	30	105	3
2	25	120	3·5

For destructive work on old boilers, tanks, girders, bridges, etc., the hand-cutter is most valuable and economical, and for ship repair work (in which time saving is the all important factor) it can be used to great advantage for the removal of damaged plates.

In construction work heavy girders and tees can be cut in place or without handling within a time which precludes older methods.

MEMOIRS.

Henry Brecknell was born in Bristol on 6th September 1856. He was educated at the Trade School, now merged into the Merchant Venturers' College, and commenced in 1870 an apprenticeship of seven years in his father's works at Bristol. On the death of his father in 1877 he became sole proprietor of the firm under the name of H. Brecknell and Son. In 1896 he was joined in partnership by Messrs. Munro and Rogers, carrying on the business under the style of Brecknell, Munro and Rogers, Ltd., first at Lawrence Hill and later at Thrissell Street, Bristol, as mechanical, electrical, and tramway engineers. His death took place at Bath, after he had been suddenly taken ill while travelling in his motor-car, on 23rd August 1916, in his sixtieth year. He was elected a Member of this Institution in 1910.

Sydney Thornton Dobson was born in London on 20th January 1866. He was educated at St. Paul's College, Stony Stratford, and at King's College School, London, and pursued his technical studies at the School of Electrical Engineering, Hanover Square, London. Having acquired some preliminary experience during a stay of twelve months with Messrs. Edmunds and Goolden, electrical engineers, he went to the Arc Works of Messrs. Crompton and Co., Chelmsford, where he served a further apprenticeship of three years, 1884–1887, acting towards the end of his time as Second Engineer at their electric lighting station at Tilbury Docks. In 1887 he joined the electrical department of the Imperial Continental Gas Association, and took charge of their Central Station in Vienna, which was at that time the largest example of the supply of electricity at low pressure and with storage batteries. On his return to England in 1889 he was appointed Chief Engineer to the St. James's and Pall Mall Electric Light Co., Ltd., a post which he held at the time of his death. In 1900,

when the Central Electric Supply Co., Ltd., was formed for the distribution of electricity in bulk, he was associated with Sir Alexander Kennedy as Joint Engineer of the scheme. He was accidentally drowned, at the age of fifty, by falling from his motor yacht in Poole Harbour, on 5th July 1916. He was elected a Member of this Institution in 1899. He was also a Member of the Institution of Civil Engineers and a Member of Council of the Institution of Electrical Engineers from 1902 to 1905.

WILLIAM ARTHUR GAWTHORNE was born at Kirkee, India, on 10th November 1868. He was educated at the Cathedral High School from 1877 to 1884, and then began an apprenticeship at the dockyard of the P. and O. S. N. Co., at Mazagon, Bombay. On its completion five years later he went to sea as Fourth Engineer with the British India Steam Navigation Co., and resigned in 1890 after receiving the Certificate for 2nd class Engineer. In the following year he became First Engineer, and joined the Irrawaddy Flotilla Co., Burma, as Second Engineer, subsequently being promoted to Chief Engineer. In 1894 he was appointed Engineer to the Madura Mills Co., and two years later became Manager and Chief Engineer to the Kohinoor Mills Co., Ltd., Dadar, India. In this capacity he superintended the building and erection of the mills and the installation of the engines and boilers. On the completion of the work he remained with the firm of Killick, Nixon and Co. for nineteen years. His death took place in London on 4th August 1916, in his forty-eighth year. He was elected an Associate Member of this Institution in 1901, and was transferred to full Membership in 1909.

WALTER JOHN HAMMOND was born at Ashford, Kent, on 21st January 1849. He served a lengthy apprenticeship with the locomotive superintendent of the South Eastern Railway Co. at Ashford, and in 1871 went to Brazil as civil engineer on the Paulista Railway, of which he became manager at the age of twenty-four. For his work in connexion with the navigation of the River Mogy-Quassu, he was made a Knight of the Order of

the Rose of Brazil by the Emperor Dom Pedro II. By contract with the Government, a slave was freed from liability to capture within the railway concessions, which were treated as English property, a regulation which led to the exposure and alleviation of many cases of cruelty. In 1887 the slaves were liberated, and at the time of the Brazilian revolution in 1888 his intimate knowledge of the country and the language enabled him to exercise a sedative influence.

After twenty-one years' uninterrupted labour in São Paulo, he returned to England in 1892 and settled at Knockholt, near Sevenoaks. He then became a director of various companies, including the San Paulo Railway, the Amazon Steam Navigation Co., etc., and in the interests of the last named, he went up the River Amazon into Peru. His death took place at his residence at Knockholt, on 11th August 1916, in his sixty-eighth year. He was elected a Member of this Institution in 1875.

Captain Lyn Arthur Philip Harris, Welsh Regiment, was born at Llanishen, Cardiff, on 9th October 1892. He was educated at Cardiff Intermediate School and Denstone College, Staffordshire, on leaving which in 1910 he became a pupil of Mr. C. T. Hurry Riches, Locomotive Superintendent, Rhymney Railway Works, Caerphilly, near Cardiff. Near the end of his pupilage he passed the Intermediate B.Sc. examination, and after its completion he studied at Cardiff University College for the final examination. On war breaking out, he joined the Public Schools Battalion of the Royal Fusiliers. On 10th December 1914 he received a Commission as 2nd Lieut. in the 16th (Cardiff City) Battalion of the Welsh Regiment, was promoted to be Lieutenant on 1st June 1915, and Captain on 4th December 1915, on which day he went out with his regiment to France. On 30th March 1916 he also became Adjutant. He was killed at the taking of Mametz Wood, France, on 11th July 1916, in his twenty-fourth year. He was elected a Graduate of this Institution in 1913.

Sec. Lieut. John Howarth, Royal Engineers, was born at

Rochdale on 10th August 1889. After receiving his elementary education at Cronkeyshaw School, Rochdale, he began an apprenticeship at the age of fourteen at the Sun Ironworks, Heywood, and four years later he became an articled pupil to Messrs. J. Diggle and Son, civil engineers, of Westminster and Heywood. On the completion of his apprenticeship in 1910, he remained as engineering assistant to the same firm, being engaged on the design and installation of various pumping and power plants for water and sewage works, also bridges and civil engineering plant. For a time he acted as resident engineer at the Salford Sewage Works. In September 1914 he joined the Army as sapper in the Royal Engineers, and rapidly became Quartermaster-Sergeant. Ultimately he was offered a Commission as Second Lieutenant in the Royal Engineers, and went to Egypt in December 1915. A few months latter he was ordered to France, where he was wounded by shrapnel. After being six weeks in hospital at Boulogne, he was brought over to the Military Hospital at Epsom, where he died on 10th September 1916, at the age of twenty-seven. He was elected a Graduate of this Institution in 1909, and an Associate Member in 1914.

Joseph Ingleby was born at Baslow, Derbyshire, on 31st January 1849. His first business experience was obtained at Owen's Patent Wheel, Tyre, and Axle Co., of Rotherham, where he remained six years. In 1871 he joined the late Mr. Henry Simon, who had not then started as a milling engineer, but in 1879 the latter introduced into England the automatic roller system for flour milling. Mr. Ingleby became Mr. Simon's chief assistant in building up the business, of which he became the head on the death of the founder in 1899. The firm was turned into a limited company in 1897, and Mr. Ingleby was one of the first directors. Two years later he became chairman, which post he held for eight years. He was a director of several other companies, and when, in 1907, he gave up the chairmanship of Henry Simon, Ltd., he retained his position as chairman of Simon-Carves, Ltd. His death took place suddenly in Manchester on 13th July 1916, at

the age of sixty-seven. He was elected a Member of this Institution in 1888.

Private Alexander Davidson Johnston, Jun., London Scottish Regiment, was born at South Shields on 24th May 1883, and was educated at local schools. In 1898 he began an apprenticeship of six years in the workshops of the Northern Press and Engineering Co., Ltd., South Shields, and in the last two years of which he was in the drawing-office. During his apprenticeship he took the evening course at the Durham College of Science, and later at the Sunderland Technical College. On the completion of his apprenticeship in 1904 he remained with the firm as draughtsman for a few months. During the college vacation in 1905 he went in a similar capacity to the works of Messrs. Vickers, Sons and Maxim, Barrow-in-Furness. In 1906 he gained a Whitworth Exhibition, and returned to the Northern Press and Engineering Co., where he was engaged on the design and development of new machinery for the automatic production of stereo-plates for rotary printing presses. Two years later he joined the firm of Henry Simon, Ltd., Manchester, and had charge of the experimental department, being responsible for the scientific development of milling machines. Subsequently he became head of the works department, where he showed great ability and promise. In December 1915 he enlisted in the 1st Battalion, 14th London Scottish, and was drafted to France in the following June. He was killed at the Battle of the Somme on 1st July 1916, at the age of thirty-three. He was elected a Graduate of this Institution in 1906, and an Associate Member in 1912.

Sec. Lieut. Thomas Booth Keyms, Royal Field Artillery, was born at Cork on 26th October 1879. He received his early education at Cork Model School and at Queen Street Collegiate Schools, and in 1896 matriculated at the Royal University of Ireland. His technical instruction was received at the Schools of Science and Art, Cork. He began his apprenticeship in 1897, at Messrs. Dübs and Co., Queen's Park Works, Glasgow, where he

also acquired two years' drawing office practice. He obtained further experience on the Caledonian Railway at their running sheds at Polmadie. On leaving Messrs. Dübs and Co., he was for a time assistant to Messrs. Strain and Robertson, Consulting Engineers, Glasgow, and from 1905 to 1908 he was in charge of locomotive and rolling stock work. He left for Brazil in the latter year, where he took up the duties of Assistant Locomotive Engineer in charge of the Southern District of the Great Western Railway of Brazil. He joined the Colours during the European War, receiving a Commission as Second Lieutenant in the Royal Field Artillery Special Reserve. While serving his apprenticeship in Glasgow he was a member of the 1st Lanark Volunteers, and while in Brazil, was a member of the Legion of Frontiersmen. His death took place in action on 19th July 1916, in his thirty-seventh year, as a result of a shell bursting at his feet in the course of artillery action where, from the report of his brother officers, he showed conspicuous bravery in carrying out his duty. He was elected a Member of this Institution in 1913.

SAMUEL EDWARD LEE was born at Limerick on 5th February 1845. He served part of his apprenticeship, from 1859 to 1863, in the works of his father's firm, Harrison Lee and Sons, City Foundry, Limerick, and subsequently as improver, from 1863 to 1866, at Messrs. Courtney and Stephens, engineers, Dublin, in their works and drawing office. On the death of his father in 1866 he returned to Limerick to take up the management of the works, in conjunction with his brothers, and on the death of his eldest brother in 1869, Mr. S. E. Lee has been senior partner and manager since that date in the general engineering and millwright business. He took a deep interest in the question of hydraulics and was a milling expert, being consulting engineer for the largest mill in the south of Ireland. He was a Justice of the Peace for Limerick. His death took place on 22nd June 1916, at the age of seventy-one. He was elected a Member of this Institution in 1890, and was a very frequent attendant at the Summer Meetings of this Institution.

Henry Coathupe Mais was born at Westbury-on-Trym, Bristol, in 1827. He was educated at a private school in Bath, and at the Bristol and Bishop's Colleges respectively, in Bristol, subsequently completing his studies under a tutor. In 1844 he was articled to Mr. W. M. Peniistone, one of Sir I. K. Brunel's chief engineers during the completion of the Bristol and Exeter Railway, and subsequently on the surveys and construction of the Wilts, Somerset, and Weymouth Railways. On the completion of his pupilage he went to Birmingham and spent eighteen months in the engineering department of the Broad Street Foundry. In June 1850, at the age of twenty-three, he, with the proprietor of this foundry, left England for Australia, and, had it not been for the unsettled financial state in Sydney at that time, they would have opened an engineering and machinery business in that city. In the following year he became Engineer to the Sydney Railway Co., which had been formed to build the line from Sydney to Parramatta. Eighteen months later he entered the service of the City Commissioners as one of the Assistant Engineers, and remained in that capacity until 1856. He then joined in partnership in a manufacturing and general engineering business in Sydney, and carried out some extensive works. In 1858 he went to Victoria and was engaged as Engineer and Manager for Messrs. Cornish and Bruce, the contractors for the construction of the Melbourne and Bendigo Railway. On its completion in 1862 he was appointed Engineer and Manager of the Melbourne and Suburban and Brighton Railway Companies, and retained these positions until the railways became the property of the State. After having spent five years in Victoria, he went to Adelaide to take the post of Engineer-in-Chief of South Australia, an office which he held for twenty-one years until his retirement in 1888. During this period he also held the position of Engineer of Water Works from 1867 to 1878 and Engineer of Harbours from 1880 to 1888. He was also responsible for the construction of 1,470 miles of railway, several lighthouses, wharves, jetties, etc. In 1882, by direction of the Government of South Australia, he made an extensive tour round the world, and embodied the result of his observations in a Report

which was laid before Parliament. He was a Justice of the Peace for over thirty-four years. In 1888 he returned to Melbourne, and commenced practice as a consulting engineer and arbitrator, in which latter capacity he acted in important disputes between railway contractors and the Governments of Victoria, New South Wales, Queensland, and Tasmania respectively. In conjunction with other works carried out, Mr. Mais made inspections of the private railway lines in South Australia, designed and erected hydraulic sluicing plant for gold mining, and was consulting engineer for several large gold milling and mining companies in West Australia. He continued in practice as a consulting engineer until December 1912, when he retired owing to indifferent health. His death took place at South Yarra, Melbourne, on 25th February 1916, in his eighty-ninth year. He was elected a Member of this Institution in 1884; he was also a Member of the Institution of Civil Engineers, and of the American Society of Civil Engineers.

Lieut. ARTHUR POYNTING, Royal Warwickshire Regiment, was born at Edgbaston, Birmingham, on 31st December 1882, being the only son of the late Professor Poynting, F.R.S. His early education was received at King Edward's High School, Birmingham, and, after a four-years' course at the University of Birmingham, he graduated as Bachelor of Science, subsequently becoming M.Sc. On leaving the University in 1905 he entered the service of the Midland Railway Co., Derby, as assistant engineer in the New Works Dept., and in the following year was transferred to the office of the resident engineer, Heysham Harbour, where he was engaged on the construction of the harbour, buildings, and permanent way. In 1910 he became Assistant Engineer at the London and St. Katharine Docks, and a year later was transferred to the head office of the Port of London Authority as assistant to the Chief Engineer. He also acted as resident engineer on the construction of that Authority's cold store in Charterhouse Street, London. He joined the Army two days after war broke out, and obtained a Commission in the Royal Warwickshire Regiment, with which regiment he had been associated while a student

at the University. He was afterwards attached to the Machine Gun Corps, and was killed in action near Pozières, France, on 25th July 1916, in his thirty-fourth year. He was elected an Associate Member of this Institution in 1913.

Richard Price-Williams was born in London on 22nd November 1827, being a son of Dr. John Morgan Williams, of Bridgend, Glam. He was educated at his native place, before serving a pupilage under the late Mr. George Heald, who was the late Mr. Thomas Brassey's engineer on the construction of the Lancaster, Carlisle, and Caledonian Railways in 1845–6. He afterwards served as an apprentice in the locomotive works of Messrs. Kitson, Thompson and Hewitson (now Kitson and Co., Ltd.), at Leeds, being engaged later on, from 1854 to 1860, in designing and preparing plans of girder bridges, and carrying out other works while resident engineer at Leeds on the Great Northern Railway. Subsequently he acted as Consulting Engineer for the proposed Metropolitan Outer Circle Railway, and in the preparation of plans and estimates for a number of other railways, both in this country and in the Colonies. He was appointed by the Royal Commission on Coal Supplies in 1866 and subsequent years to prepare evidence of their duration, and for the Royal Commission on Irish Railways in 1868 he was appointed Chief Engineer to examine and value them. He also acted for most of the principal railway companies in the United Kingdom to prepare and advocate their claims against the Government for the purchase of the telegraphs in 1871. In 1889 he reported upon the condition of the railways in New South Wales and Tasmania, and afterwards acted as arbitrator on behalf of the Tasmanian Main Line Railway Co. for the disposal of the railway to the Tasmanian Government, being subsequently appointed Consulting Engineer by the Governor.

Mr. Price-Williams' name will always be associated with the introduction and development of the Bessemer process in this country. His early connexion with the construction of railways led him to make railway engineering his own particular branch from the commencement of his practice. His written contributions

and his continual personal efforts were greatly instrumental in inducing the British railway engineers to make a trial of the Bessemer steel rails in place of the iron rails which were so short-lived under heavy traffic. Sir Henry Bessemer appreciated his services, and appointed him manager of the first Bessemer steel works put down at Greenwich. Apart from his engineering activities, Mr. Price-Williams did a large amount of statistical work on a variety of subjects, and was for many years a Member of Council of the Royal Statistical Society.

He became a Member of this Institution in 1859, and served as a Member of Council from 1880 to 1887. At the Annual General Meeting this year the President announced that the Council had nominated him as an Honorary Life Member in recognition of his services in connexion with railways. In 1879 he presented a Paper to this Institution on "The Economy of Railway Working," but the greater number of his Papers on this question were read before the Institution of Civil Engineers and the Royal Statistical Society. He became a Member of the former Institution in 1861, and was awarded the Telford, Watt, and Stephenson gold medals. The Iron and Steel Institute awarded him the Bessemer gold medal in 1898 on the recommendation of Sir Henry Bessemer. He died at Bournemouth on 19th September 1916 (within two months of entering his ninetieth year).

Matthew Sydney Smith was born in London on 14th April 1876, and was educated at schools in South London. His apprenticeship, of eight years, was served with Messrs. James Simpson and Co., Ltd., London; after which the same firm transferred him, in 1889, to assist in laying out and erecting their new works at Newark, and later to superintending the Order Department and Works Drawing Office. In 1904 he left Newark to take up the post of engineer to Messrs. Welch, Perrin and Co., of Melbourne, the Victorian Agents for various Australian and British firms, and in June 1913 he entered the service of Simpson Brothers, Australian representatives for Messrs. James Simpson and Co., Ltd., and the Worthington Pump Co., Ltd. His death took place at Sydney, on 20th November

1915, in his fortieth year. He was elected an Associate Member of this Institution in 1905; and was a Member of the Victorian Institute of Engineers.

Sec. Lieut. Frank Trevor Wilkins, 13th Northumberland Fusiliers, was born in Birmingham on 8th March 1890. He was educated at King Edward VI School in his native city, and gained a Foundation Scholarship there in 1900. On leaving school in 1906 he was apprenticed for five years in the marine-engine works of Messrs. Vickers, Ltd., Barrow-in-Furness, and during the greater part of this time he studied at the Barrow-in-Furness Technical School. In 1909 he left Barrow to complete his apprenticeship at the University of Birmingham, and having taken his B.Sc. degree in Mechanical Engineering in 1912, he returned to Barrow for three months' work in the drawing-office. In October of the same year he obtained a Bowen Research Scholarship in Engineering at the University of Birmingham, where he took a M.Sc. degree in 1914. During the period he was at Birmingham he was a Member of the University Officers' Training Corps, and soon after the outbreak of the war he received a Commission as Second Lieutenant in the 13th Northumberland Fusiliers, proceeding shortly afterwards to Egypt. In 1916 he was transferred to France, being attached to the 1st Border Regiment, and took part in the great attack on 1st July, when he died from wounds received in action, at the age of twenty-six. He had prepared a Paper on "Trials of a Diesel Engine," which had been accepted by the Council for reading and discussion at a Meeting. This Paper * was the outcome of experiments he had made at the University of Birmingham, and was presented at the Meeting in October by Professor F. W. Burstall, under whose supervision the trials had been made. He was elected a Graduate of this Institution in 1913.

Edward Malcolm Wood was born at Skelton-cum-Newby, Yorkshire, on 28th September 1839. He served an apprenticeship

* Proceedings 1916, page 587.

of four years in the works of Messrs. Robert Stephenson and Co., Newcastle-on-Tyne, and was subsequently engaged there for a year as draughtsman. He next became draughtsman at the works of Messrs. J. Fowler and Co., Leeds, and two years later became a member of the engineering staff of Sir John Fowler, of Westminster. After nine years' service he went to Egypt as Assistant Engineer on the Sudan Railway, which position he held for four years, when he returned to England and practised as consulting engineer in Westminster. In this connexion he was associated for many years with Sir John Fowler, Sir Benjamin Baker, Sir William Arrol, etc., in their engineering work. During the last two years he acted as consulting engineer on questions dealing with the Forth Bridge, and was a well-known authority on iron and steel and general engineering. On the occasion of the Summer Meeting of this Institution in Edinburgh in 1887, he read a Paper on "The Structure and Progress of the Forth Bridge." His death took place in London on 27th July 1916, in his seventy-seventh year. He was elected a Member of this Institution in 1881.

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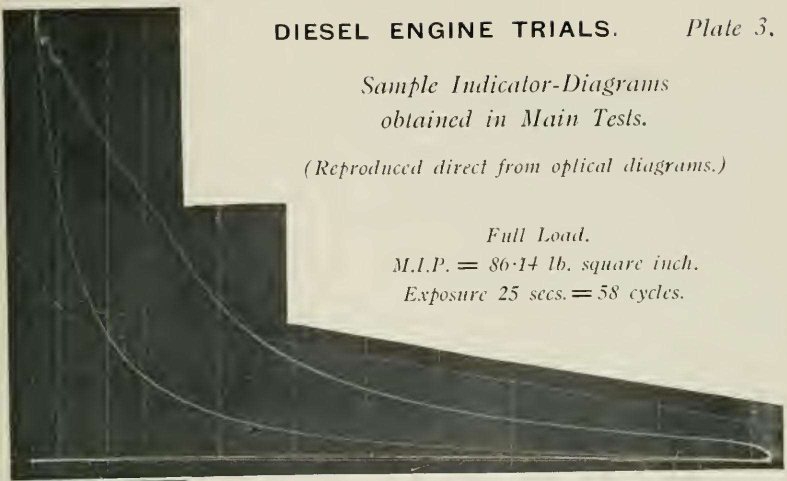
1916.

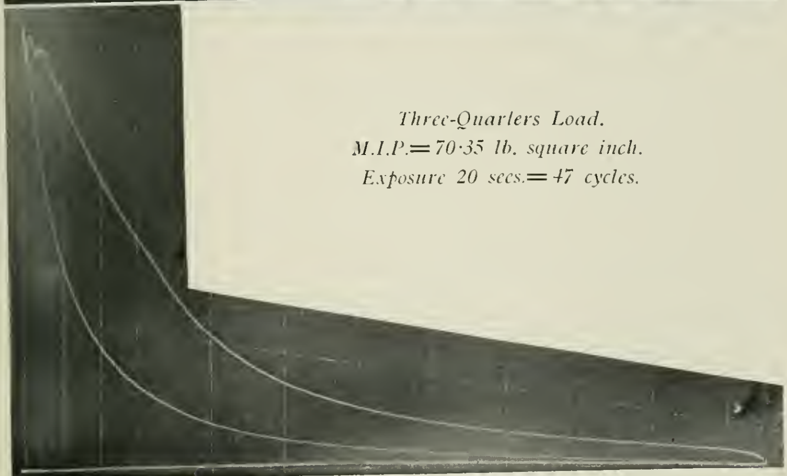
October–December.

Sample Indicator-Diagrams obtained in Main Tests.

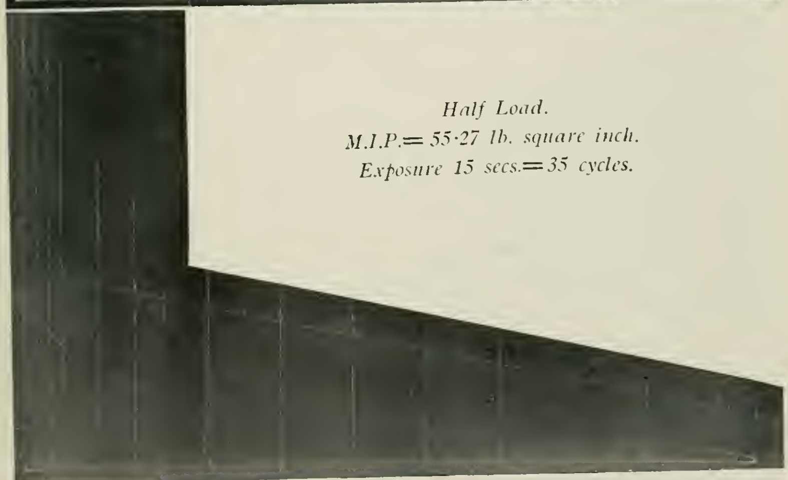
(Reproduced direct from optical diagrams.)



Full Load.
M.I.P. = 86·14 lb. square inch.
Exposure 25 secs. = 58 cycles.

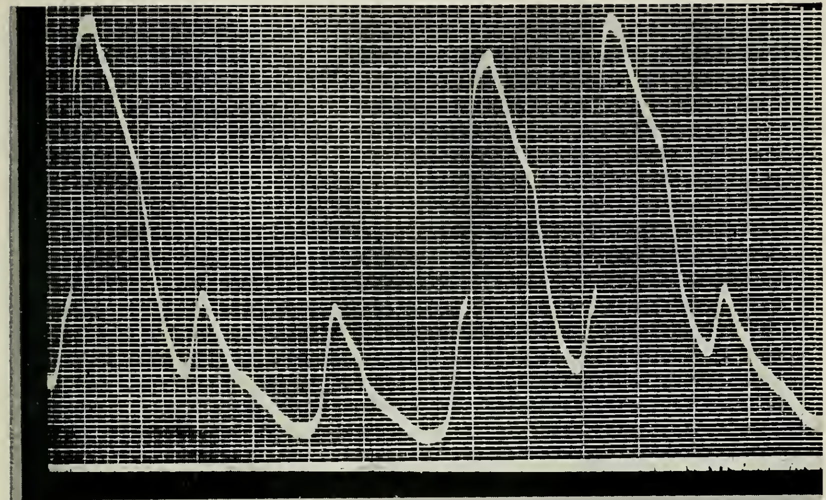


Three-Quarters Load.
M.I.P. = 70·35 lb. square inch.
Exposure 20 secs. = 47 cycles.

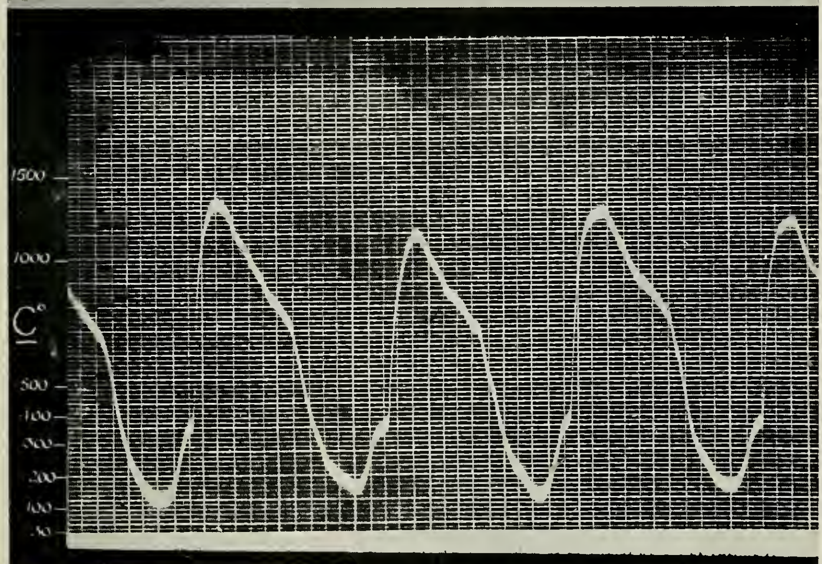


Half Load.
M.I.P. = 55·27 lb. square inch.
Exposure 15 secs. = 35 cycles.

(Professor E. G. Coker's remarks.)



Temperature changes in the charge of a gas-engine cylinder for several cycles when the governor is acting (not calibrated).



Temperature changes in the charge of a gas-engine cylinder when explosions occur at every stroke.

Fig. 1. *A District of London, 1809-14.*

a. Brick Lane gasometer.
b. Norton Folgate ,,
c. Westminster ,,
A B.C. Inter-communication junctions between a.b.c.
—— Principal gas mains.
------ Branch ,, ,,

1. River Thames.	5. Haymarket.
2. Strand.	6. Coventry St.
3. Whitehall.	7. Piccadilly.
4. Charing Cross.	8. St. James's St.
9. Pall Mall.	

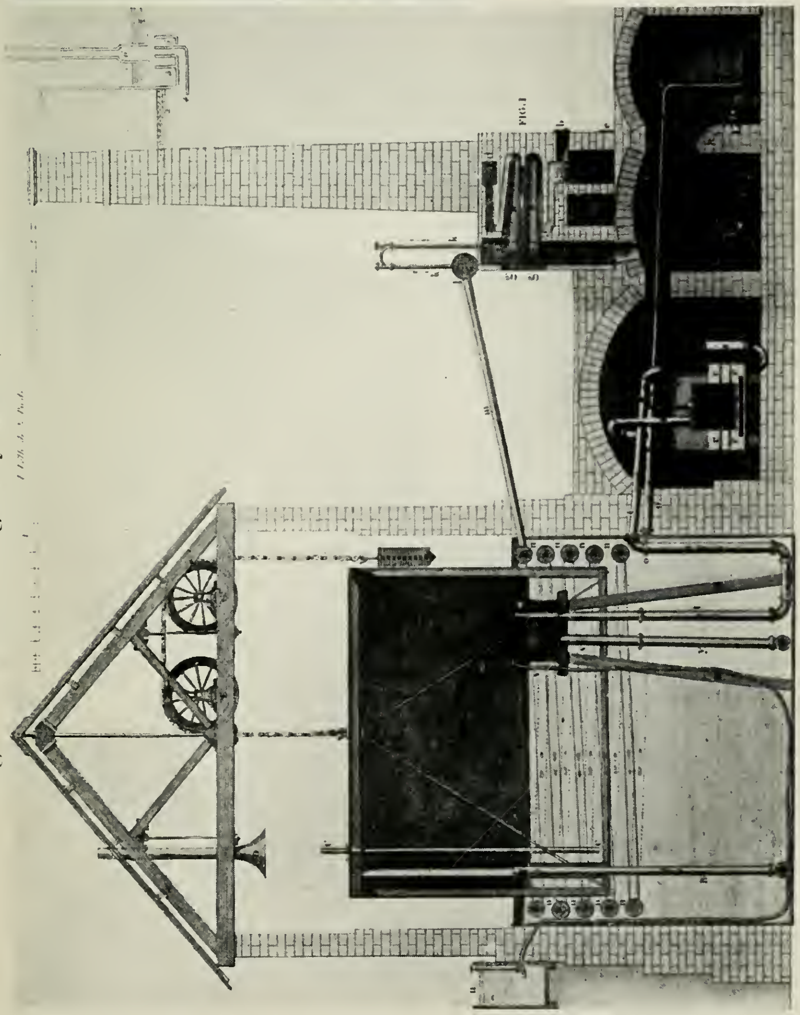


Fig. 2. *Gasometer designed by Winsor, 1809-14.*

Mechanical Engineers 1916.

(*Photos from the original engravings, Traité pratique, 1816*)